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INTERSTATION

COMMUNICATIONS STUDY

FOR DEEP SPACE

INSTRUMENT FACILITIES

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COLLINS RADIO COMPANY

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INTERSTATION COMMUNICATIONS STUDY

FOR

DEEP SPACE INSTRUMENT FACILITIES

Section I

INTRODUCTION

This document outlines the results of a study, conducted by Collins Radio Company for the Jet Propulsion Laboratories as part of Contract M-27903, to aid JPL in defining an optimum communication system to be used for interconnecting three Deep Space Instrument Facilities (DSIF) located at Goldstone, California, Woomera, Australia, and Johannesburg, South Africa.

The results of the study are to be used in determining (1) whether each DSIF station is to be autonomous in that it possesses its own intelligence center capable of generating deep space probe command information based upon interpretation of information previously received from the probe or, (2) if it is to have wideband communications with a centrally located intelligence center which performs this function for all three DSIF stations. When the DSIF stations possess their own intelligence center, the facilities required for communicating between DSIF stations can consist of low data rate (TWX) and/or voice channels. When the DSIF stations are dependent upon a centrally located intelligence center for generation of probe command information, the facilities required for communicating between stations and the intelligence center must be capable of higher data rates and refined reliabilities.

A comprehensive study of the costs, availability, reliability, and information rate capability of both leased and privately owned facilities has been made to enable the Jet Propulsion Laboratories to decide on the type of interstation communication system to employ. Several common carriers offering leased services between the required locations have been querried concerning the four items listed above and the results are incorporated in Section IV of this report. In addition, the magnitude of these items have been determined for privately-owned facilities for a three, four, five, and six station complex. The three station complex investigated consists of stations located at each of the three DSIF station locations: Goldstone, Woomera, and Johannesburg. The four station complex investigated consists of stations located at each of the three DSIF station locations, plus a relay station located in the vicinity of Patrick Air Force Base, Florida. The PAFB station will function strictly as a relay station, and will be connected to the Goldstone DSIF station by wire lines. The five station complex investigated consists of the four station complex plus a relay station located near Antofagasta, Chile, which would serve as a dual purpose relay in that it could relay to either the Woomera or the Johannesburg DSIF station. The six station complex investigated consists of four station complex, plus a West relay station located in the Hawaiian Islands and an East relay station located at Ascension Island.

This report describes the approach used in performing this study. Section II describes the types of communication facilities studied, Section III gives the details of the propagation and reliability study performed, Section IV describes the service or equipment used in the study, Section V details the costs of the different services investigated, Section VI contains the summary of the study, and Section VII states the conclusions.

Section II

TYPES OF COMMUNICATION FACILITIES

1.   GENERAL REQUIREMENTS.

The communication facilities ultimately selected by the Jet Propulsion

Laboratories must provide reliable point-to-point communications between the three

Deep Space Instrument Facilities located at Goldstone, California; Woomera,

Australia, and Johannesburg, South Africa.   The selection of the final system will

be made from a list of representative systems and will provide one of the thirteen

services listed below.

    1.   Two leased TWX channels

    2.   Two privately-owned TWX channels, plus one privately-owned 1 kc voice
        channel

    3.   Two privately-owned TWX channels, plus two privately-owned 5 kc
        analog channels

    4.   One hundred fifty bits per second digital channel

    5.   One thousand fifty bits per second digital channel

    6.   Three thousand bits per second digital channel

    7.   Five thousand twenty-five bits per second digital channel

    8.   Ten thousand fifty bits per second digital channel

    9.   One hundred cps bandwidth analog channel

   10.   One thousand cps bandwidth analog channel   .

   11.   Three thousand cps bandwidth analog channel

   12.   Five thousand cps bandwidth analog channel

   13.   Ten thousand cps bandwidth analog channel

A study of the communication capabilities of both leased and privately owned facilities has been made, and the results of this study tabulated in tables 6-1 through 6-4 and are shown graphically in figure 6-1 through 6-4 in Section VI of this report.

2.   LEASED FACILITIES.

Facilities available for leasing from common carriers utilize wire lines, high frequency radio and combinations of the two. For example, the routing of a message from Goldstone, California, to Woomera, Australia, would be via wire lines to San Francisco, California, h-f radio to Sydney, Australia, and wire lines to Woomera, Australia. Major advantages offered by leasing of facilities from common carriers include:

1.   Small expenditures for capital equipment.

2.   Facilities may be released when the requirements have ceased.

Major disadvantages of leasing facilities from common carriers include:

1.   Customer has no control over equipment outage times.

2.   Facilities of more than one commercial carrier required. Therefore, the overall reliability is dependent upon the poorest facility with the possibility that outage times for all carriers may occur in series rather than parallel.

3.   Maximum data rates and bandwidths are restricted to existing facilities.

3.   PRIVATELY-OWNED FACILITIES.

Facilities that can be privately owned consist of international radio facilities. Because of the distances separating the DSIF station locations, the only economical approach is to use high frequency radio circuits for communications between these stations. For a three-station communications complex, it is possible for all communications to be carried by radio circuits. For the other complexes studied, leased lines will be required between the Goldstone DSIF station and the relay station

located in Florida. Major advantages offered by privately-owned facilities include:

1. Greater capability and versatility in that it may be modified for use with any specific program.

2. Readily available when required.

3. Maintenance can be scheduled for periods of inactivity.

4. Reliability is dependent upon the reliability of the radio circuits.

Major disadvantages of private owned facilities include:

1. Expenditure for capital equipment.

2. Maintenance costs continue during periods of inactivity.

Section III

PROPAGATION STUDY

1.   OBJECTIVE

This report presents the results of a HF propagation study to determine the

communication reliability of a communications net which will permit an exchange of

information between both Goldstone-Johannesburg and Goldstone-Woomera.   Communi-

cation reliability is defined as the percentage of the year that Goldstone can conduct

99.9 per cent quality communication with both Woomera and Johannesburg,   either

directly or through terminals and/or relays; (paragraphs 2c and 2d contain complete

definitions of communication quality and reliability).   Factors which must be taken

into consideration for the achievement of this objective are:

1.   Time period involved

2.   Bandwidths (information rates) and method of coding (digital or analog)

3.   Permissible error rate

4.   Transmitter power and antenna gain

5.   Effect of added terminals and/or relays

The first three of these factors have been specified by JPL; the only remaining

variables are transmitter power and antenna gain, and the geographical configuration

of expanded communication complexes.   Therefore, the conclusion of this propaga-

tion study will state communication reliabilities (parametric in time, bandwidth,

coding, error rate, transmitter power and antenna gain) for those geographical

configurations which were considered practical.   No attempt has been made to obtain

an optimum geographical configuration strictly on the basis of reliability since budgetary limits and logistics also influenced the number and location of suitable terminal and relay sites.

2.   GENERAL CONSIDERATIONS.

  a.   TIME PERIOD INVOLVED.

The time period involved, calendar year 1962, is important in that the cyclic solar activity will influence critical frequencies and absorption. By plotting the mean annual Zurich sunspot numbers since 1946, the eleven year cyclic trend was established and a predicted value of 69 was estimated as the mean annual sunspot number for 1962; see figure 3-1. A plot of the annual means dating back to 1835 revealed that this procedure is sufficiently accurate for the intended use.

  b.   BANDWIDTHS (INFORMATION RATES) AND METHOD OF CODING
        (DIGITAL OR ANALOG)

The bandwidths that were investigated may be summarized as follows:

Digital channels	Analog channels
0.1 kc	1.0 kc
1.0 kc	3.0 kc
3.0 kc	5.0 kc
5.0 kc	10.0 kc
10.0 kc	

Digital channels were assumed to employ binary coding with predicted wave signaling techniques, which represent the latest advance in the present state of the art. Bit rates corresponding to a particular bandwidth for the digital channels may be obtained from the classic equation using a signal-to-noise ratio of unity.

$$C = BW \log_2 \frac{S + N}{N}$$

C = channel capacity in bits per second

BW = bandwidth of facility in cycles per second

It should be pointed out that the projected performance of digital techniques can be based upon a wealth of published experimental results, where as this background is not available for the analog coding techniques. In addition, the advantages of diversity receiving techniques are probably not realized to the same degree with analog coding.

c.   PERMISSIBLE ERROR RATES.

The maximum permissible error rate has been standardized as 0.1 per cent in this study, and shall hereafter be referred to as a communication quality of 99.9 per cent. Communication quality of 99.9 per cent inplies that of 1000 transmitter bits a minimum of 999 will be received correctly. This definition is applicable only to digital coding techniques, and a corresponding definition to evaluate the quality of an analog channel cannot be stated as precisely.

d.   TRANSMITTER POWER AND ANTENNA GAIN.

Based on past experience, a transmitter power of 10 kw was selected for use throughout this study. Antenna gains (transmitting and receiving) were assumed to be 9 db, which is quite representative of a number of h-f antennas in present use. A specific antenna type, classed as the logarithmic periodic structure is considered particularly suitable for the intended applications. However, the calculations are applicable to any h-f antenna with a comparable gain.

e.   EFFECT OF ADDED TERMINALS AND/OR RELAYS.

This factor comprises the bulk of the propagation study, and is evaluated by the communication reliability percentage. An explanation of communication reliability percentage rather than a definition is necessary for full appreciation of the interplay of factors involved.

Consider all stations in the DSIF communications complex including terminals and relays, if applicable, in continuous operation for a period of one year. The communication reliability is the percentage of the year that Goldstone can conduct 99.9 per cent quality communication with both member DSIF's, either directly or through a terminal, relay or member DSIF.

Since at least two operational DSIF links are required for a complete circuit, the communication reliability percentage at any particular instant must necessarily be based on the link with the greatest signal degradation. This procedure, plus the inherent pessimism of the Signal Corps long term propagation predictions (used in conducting this study) permit the stated communication reliability percentages to be considered as expected minima. The circuit outage time which is responsible for the varying communication reliability percentage is caused either by ionospheric nonsupport of propagation or excessive absorption and invariably affects only two of the three basic DSIF links. Outage time when present will occur in a rather orderly manner, usually on a daily basis. Its appearance and extensiveness are dependent upon the equinox or solstice seasonal period involved.

Solar activity, which cannot be predicted except on a statistical basis, may hamper communications for short intervals. However, an allowance for this factor has been included in the communication reliability percentages. Sudden ionospheric disturbances may occur without warning and will degrade circuit performance during daylight hours. Magnetic storms will also degrade circuit performance, but NBS in Boulder, Colorado issues warnings which predict the condition at least 48 hours in advance.

2. TERMINAL AND RELAY SELECTIONS.

a. SELECTION CONSIDERATIONS.

The terminal and relay locations chosen for expanding the basic three-station complex and the considerations which led to their selection are listed below:

Patrick (terminal)	1.	can be conveniently tied to Goldstone by hard line
	2.	proximity to Cape Canaveral
	3.	logistically excellent
Hawaii (relay)	1.	practically a Hobson's choice--only alternative is Guam
	2.	logistically good
Ascension (relay)	1.	last station in the Atlantic missile dowrange system
	2.	logistically fair
Antofagasta (relay)	1.	present site of a U. S. Minitrack station
	2.	may serve as a dual purpose relay
	3.	logistically fair

b. OTHER SITES CONSIDERED.

A number of other relay sites were considered, and are listed to indicate the field from which the aforementioned sites were selected.

Recife, Brazil

Puerto Rico

Guam

Christmas Island (USA)

Maldive Islands

Dakar, F. W. A.

Of these, only Puerto Rico and Guam are considered worthy of special mention.
Time did not permit an analysis of their effectiveness relative to the sites actually
studied. However, it is quite doubtful that any significant improvements would be
imparted.

    (a)   Puerto Rico may prove to be an excellent relay for the Goldstone-
Johannesburg link if a stateside terminal (Patrick) cannot be established.

    (b)   If Guam can be considered on a logistic level with Hawaii, its use in
place of Hawaii would mildly improve the Goldstone-Woomera link.

4.   PRELIMINARY EVALUATION OF EACH COMPLEX.

    a.   CRITERIA.

Rather than completely evaluate the communication reliability percentage for
each complex considered, a relatively simple criterion was established for rejection.
Coincidental outage time (two links out simultaneously) resulting from nonsupport of
propagation will isolate Goldstone from at least one DSIF. The coincidental outage
time which exceeds the coincidental outage time of the basic ·· three-station complex
(stations at the three DSIF's) affords a basis for rejection. In addition, total outage
time must be kept in mind, for an excessive amount indicates an inherently weak link.

A minimum of coincidental outage time is a necessary, but not sufficient condi-
tion for the selection of an optimum complex. It is conceivable that a complex may
employ an extra relay which does not reduce the coincidental outage time appreciably
but which provides a gain in received signal strength sufficient to justify its inclusion.

    b.   OUTAGE TIME FROM NONSUPPORT OF PROPAGATION.

Outage time resulting from nonsupport of propagation as used in this report
occurs when the E-layer penetration frequency (E-layer cutoff) exceeds the F2-layer
FOT. A degree of conservatism has been injected by excluding periods when the

difference, F2-FOT minus E-cutoff, is less than 4 mc. The stated outage times are thus pessimistic in two respects:

1. F2-FOT was used rather than F2-MUF

2. Restrictions to bands of 4 mc and less were excluded

E-layer penetration frequencies and F2-layer FOT's were obtained by standard methods for sunspot numbers 0 and 130 from Technical Report No. 8 issued by the Signal Corps Radio Propagation Agency. Nomogram conversion to sunspot number 69 was accomplished, and the results were tabulated on IBM cards. This required the frequencies to be quantized in 2 mc steps along with the normally quantized 2 hour time periods.

c. OUTAGE TIME INVESTIGATION RESULTS.

Various links were presented to the IBM 604, and the printed results were very descriptive in a graphical sense, as shown in figure 3-8. Figures 3-9 and 3-10 contain the composite results of the outage time investigations, and an interpretation of these follows.

A rapid evaluation of figures 3-9 and 3-10 is in itself sufficient to reject Antofagasta as a relay, in spite of its dual purpose role. When this drawback is compounded with the expected logistical situation, there is nothing to justify further consideration of this site. Attention will thus be focused on an expansion employing combinations of Patrick, Hawaii, and Ascension. Figure 3-11 charts the reduction in coincidental and total outage time as the terminal and relays are brought into play. Although justification for Patrick and Hawaii becomes quite apparent, Ascension adds very little to the cause. Ascension, however, will be carried forth for signal strength analysis with intuitive reasoning as the justification.

Figures 3-9 and 3-10 are based on the use of four operating frequencies, which fall within the following four frequency bands:

8 - 10 mc

12 - 14 mc

16 - 18 mc

20 - 22 mc

It is recommended that the operating frequencies be spaced at intervals of not less than 4 mc; intervals less than this are undesirable even though they fall within the allowable frequency bands:

The one-hop (F2-Layer) links between Goldstone-Hawaii and Johannesburg-Ascension present no problems regarding operating time, operating frequencies and signal strengths.

5.   FINAL EVALUATION OF EACH COMPLEX.

a.   RECEIVED SIGNAL STRENGTHS

The next step in the selection of a suitable complex is to determine the received signal strengths for the various sites in a manner which will permit a signal-to-noise conversion for the specified bandwidths.

The variation of absorption with frequency must be accounted for if accurate received field strengths are to be determined. A complete accounting becomes very involved since it would require the assignment of a number of operating frequencies to each station in the complex for a 24-hour period, and these would vary according to the complex studied. This situation forced a compromise to be effected in the interest of completing the study within the available time. The only operating

frequency used in this study and though it might be argued that this choice is a bit high, justification is based on the fact that experienced station operators will normally work above the pessimistically predicted frequencies.

Determination of the received signal strengths can be accomplished by the simple but time consuming process described in section 7.7 of NBS circular 462. The entire method is straightforward and the only chance for deviation is in selecting the values used in calculating the solar activity factor. The values used in this study were as follows:

predicted annual mean sunspot number 69

$Q = 1 + 0.005(69) = 1.3b$

$J = 1.15$ (dependant upon terminal location)

$Ad = JQKd$

Kd is obtained from absorption charts and nomograms.

The tabulated values of received signal strengths, figure 3-12, must be interpreted with the following factors in mind:

(1) ERP is 90 kw

(2) values are db above 1 uv/m

(3) values correspond to hourly median values for 50 per cent of the days

From a practical standpoint, these tabulated values are not significant until a specific bandwidth and threshold are defined.

b. SIGNAL TO NOISE.

The presence of atmospheric, galactic and man-made noise necessitates an adjustment of signal-to-noise ratios, but exact compensation for these factors becomes quite involved. However, assuming a sacrifice of the total receiving antenna gain

(9db) permits the further assumption that noise variations will not exceed 1 uv/m. This exchange is extremely liberal a major portion of the time.

The required nonfading carrier-to-noise ratio for 90 per cent intelligibility of low grade double sideband radiotelephony establishes the reference threshold at the generally accepted value of 13.8 db, and, as previously justified, the 13.8 db is referred to a noise level of 1 uv/m. (14 db was used for all calculations.)

c. BANDWIDTH CONVERSIONS

Bandwidth conversions relative to the reference threshold are based on experimental service gains established by the Signal Corps. The table given below is based on 9C.9 per cent communication quality and the use of a two element space diversity receiving system.

Bandwidth	Signal in db above reference level of 1 uv/m
1.5 kc	9 db
1.7 kc	9 db
1.7 kc	11 db
3.0 kc	12 db

(1.7 kc rows bracketed) 10 db (See figure 3-13)

Signal Corps data was not available for the 0.1 kc bandwidth, but since the Signal Corps data and Collins Kineplex data at other bandwidths were in good agreement, a Collins based value of -1 db was assigned to the 0.1 kc bandwidth.

The establishment of signal-to-noise ratios for the analog situation lacks the solid foundation of previous experimental data. A signal-to-noise reference threshold of 20 db was selected and bandwidth conversions are obtained by adding 6 db to the corresponding digital bandwidth signal-to-noise ratio.

13.8 db digital threshold + 6 db = 20 db analog threshold.

No attempt has been made to define communication quality for analog coding.

d. RELIABILITY PERCENTAGES

The combined effects of sky wave fading are accounted for in figure 3-14, this plate, in conjunction with the calculated received signal strengths, was used to obtain the quarterly reliability percentages.

For example:

1 kc digital bandwidth-threshold 6 db (for 99.9 percent communication quality)

6 db is the signal-to-noise ratio required for 50 per cent of days reliability

For a two-hour time block signal-to-noise ratio of 25 db, read 92 per cent of days reliability

For a two-hour time block signal-to-noise ratio of 0 db, read 32 per cent of days reliability

Each quarterly two-hour time block was converted to per cent of days reliability in a like manner but only if figure 3-9 indicated that propagation was supported during this period. Nonsupport of propagation results in zero per cent of days reliability and must be entered and averaged as such. Quarterly averages are obtained on the basis of the following:

(1) Within a two-hour time block for a three-station complex with all three links supporting propagation, select the intermediate value of per cent of days reliability, since the weak link will not be used.

(2) Within a two-hour time block for a three-station complex with only two links supporting propagation, select the lowest value of per cent of days reliability.

(3) Within a two-hour time block for a three-station complex with only one or no links supporting propagation, enter zero per cent of days reliability and include in the average.

An expansion of this criterion was utilized for the four-and six-station complexes.

A yearly average is formulated on the average quarterly averages. Figures 3-15 and 3-16 present the bandwidth vs communication reliability percentage for digital and analog coding techniques for the year 1962.

The use of Ascension as a relay between Patrick and Johannesburg is now justified on the basis of increased signal strength. Since a minimum improvement of 6 db is realized when absorption is slight, and a greater improvement is provided when absorption becomes significant (figure 3-12), Substitution of 40-kw transmitters (6 db increase) at Patrick and Johannesburg is not considered an expedient which would warrant the elimination of the Ascension relay.

Figures 3-15 and 3-16 represent the objective toward which the entire study has been directed thus far.

6.   ADDITIONAL CONSIDERATIONS.

Accurate knowledge of monthly circuit outage times may be obtained three months in advance by use of CRPL series D propagation predictions. The use of these predictions will only slightly modify the communication reliability percentage charted on figures 3-15 and 3-16. However, the option of excluding circuit outage time by not attempting to operate is presented since the accuracy of the predictions is quite good. If this option is exercised, an apparent communication reliability percentage results i.e. reliability when communication is supported. Figures 3-17

and 3-18 show bandwidth vs apparent communication reliability percentage. The distinction between communication reliability percentage and apparent communication reliability percentage must be kept in mind when comparisons are made.

Since all the stated communication reliability percentages have allowed for ionospheric disturbances caused by solar activity, an additional refinement may be applied if forewarnings are available. Of the two ionospheric disturbances (SID's and magnetic storms), only magnetic storms can be predicted.

NBS in Boulder, Colorado, anticipates 25 magnetic storm disturbances per year with a duration of approximately 36 hours. They also anticipate 30 magnetic storm warnings per year, normally supplied 48 hours in advance of the actual ionospheric disturbance. Warnings are promulgated by air mail and teletype.

The severity of these disturbances is variable, consequently a precise improvement in reliability cannot be determined. A 48-hour advance warning should permit effective mission "scrubbing" with a minimum of last minute confusion.

Mention has been made of obtaining, if possible, one and two month improvements to the three month CRPL series D propagation predictions for further reliability improvements. After due consideration, it has been decided that these refinements, if available, would add very little to the cause. NBS has attained an accuracy with the three month predictions which render shorter term predictions of little consequence.

A minimum of solar activity is expected during the years 1964 and 1965, and this will require a revised set of calculations for the prediction of operating frequencies and D region absorption will decrease during this period, and the over all effect will be a slight degradation in propagation conditions as compared to the year 1962.

The recommendation of sophisticated redundancy in conjunction with an error correcting scheme for the mitigation of multipath interference has been tentatively rejected in favor of a transmitting and receiving refinement. It is felt that the employment of frequency and space diversity techniques will improve performance to a level which approaches that realized by the applications of error correcting equipment, and yet not add appreciably to the cost and complexity of the terminal gear.

At an error level of 1 in 10^3 bits, the addition of an error corrector would result in an equivalent transmitter power increase of only approximately 2 db. Since bit error rates of 1 in 10^5 or 1 in 10^6, where more significant improvement would be obtained, are not required in the present system, the complete equipment required for error-correcting encoding and decoding does not appear justified. Analysis shows that most of the advantages sought by the use of error correcting codes can be obtained through the proper use of frequency diversity.

It is desired to increase the useful periods of transmission by providing more reliable communication during the opening and closing few minutes of a path which are characteristically marked by severe multipath fading. To this end the use of bit to bit frequency diversity prevents the loss of successive bits of the transmission in a single fade period. The high inherent bit to bit correlation in the data resulting from the encoding of a signal scanned from a photograph can then be used to restore missing bits. It can be shown that bit to bit frequency diversity of this type will provide improved operation equivalent to a transmitter power increase of 10 db at error rates of 1 in 1,000.

An effective increase in transmitter power achieved either by actually increasing the transmitter output or by the use of frequency diversity or error

correcting codes as indicated above will improve over-all circuit reliability by providing acceptable copy during those periods at the beginning and end of a time period when the ionosphere will support transmission, but which are characteristically marked by rather poor signal strengths and severe fading. Characteristically, as the E-layer penetration frequency decreases, permitting the transmission of high frequency radio signals over long distance by means of reflections from the F_2 layer, a short period of unstable signals occurs which will be followed by a relatively long period of stable conditions. Again, as conditions change, a short period of poor unstable signals will exist before transmission becomes impossible on the chosen frequency. It is apparent that improvement of signal-to-noise ratios during the poor signal periods will increase the total percentage of time when the circuit is useable. It is also apparent that this increase will be relatively slight since the duration of the stable signal periods is long compared to the duration of the poor signal condition. These effects are clearly apparent in the tables included at the end of this section. An evaluation of circuit reliabilities over the circuits considered in this study indicate that an effective increase of 10 db in transmitter power will result in increases in circuit reliability up to 6% at the error level of 1 in 1,000 which has been accepted as standard.

With high bit to bit correlation expected, an error corrector in its simplest form may be used in conjunction with frequency diversity. Assuming the proposed encoding of amplitude signals into eight levels, this simple error corrector or modifier "prints" levels which are the averaged values of the flanking levels when a level has been lost in transmission. Slight errors will be introduced by this method when the integrated levels are correct and sharply contrasted; however, more errors will be corrected (or modified) than introduced.

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(4) Proposal for A World Wide HF
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    No. 1178

(5) Simplified Procedure for HF Propagation Predictions

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    No. 956
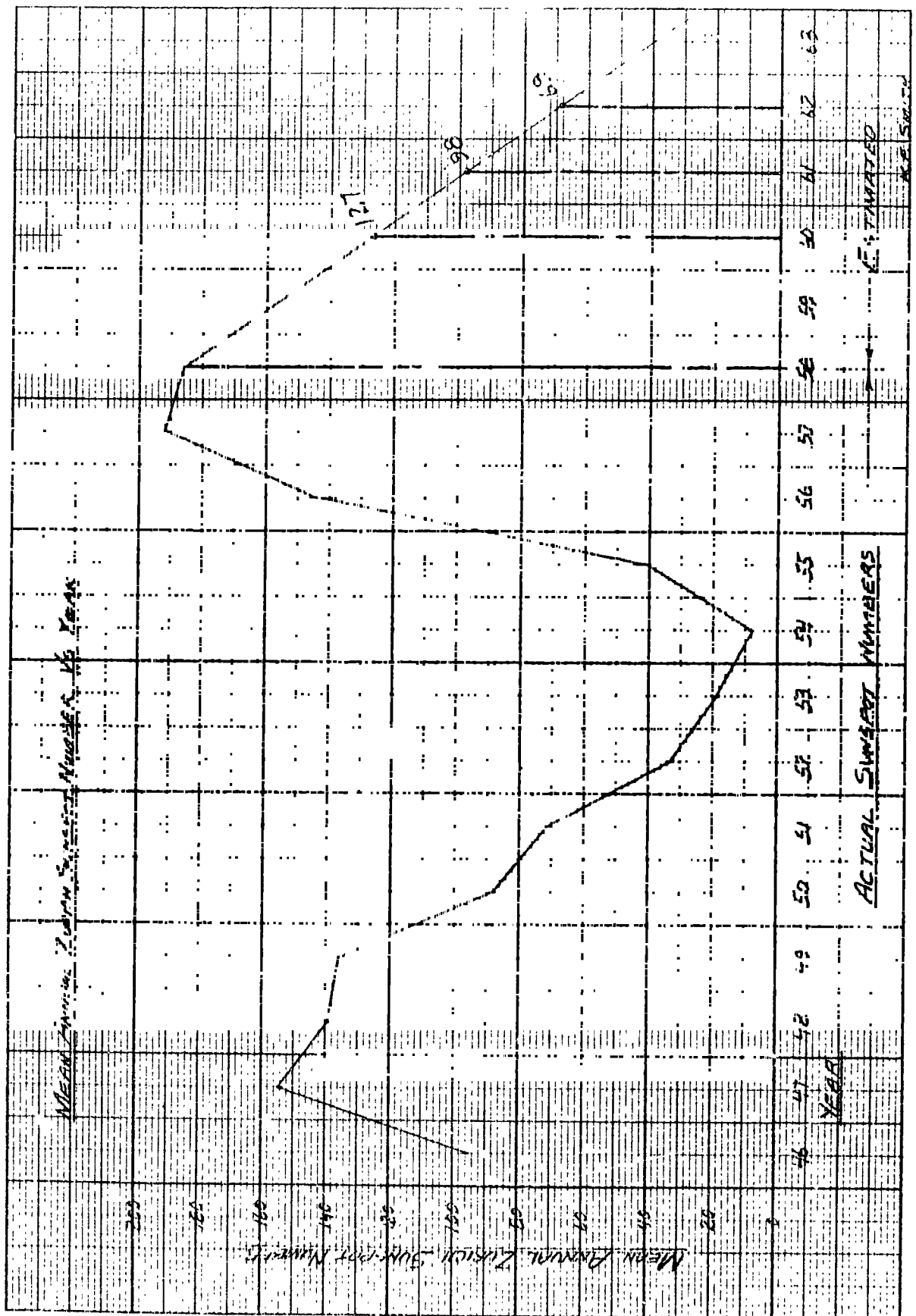
Figure 3-1. Mean Annual Zurich Sunspot Number, 1946 through 1963
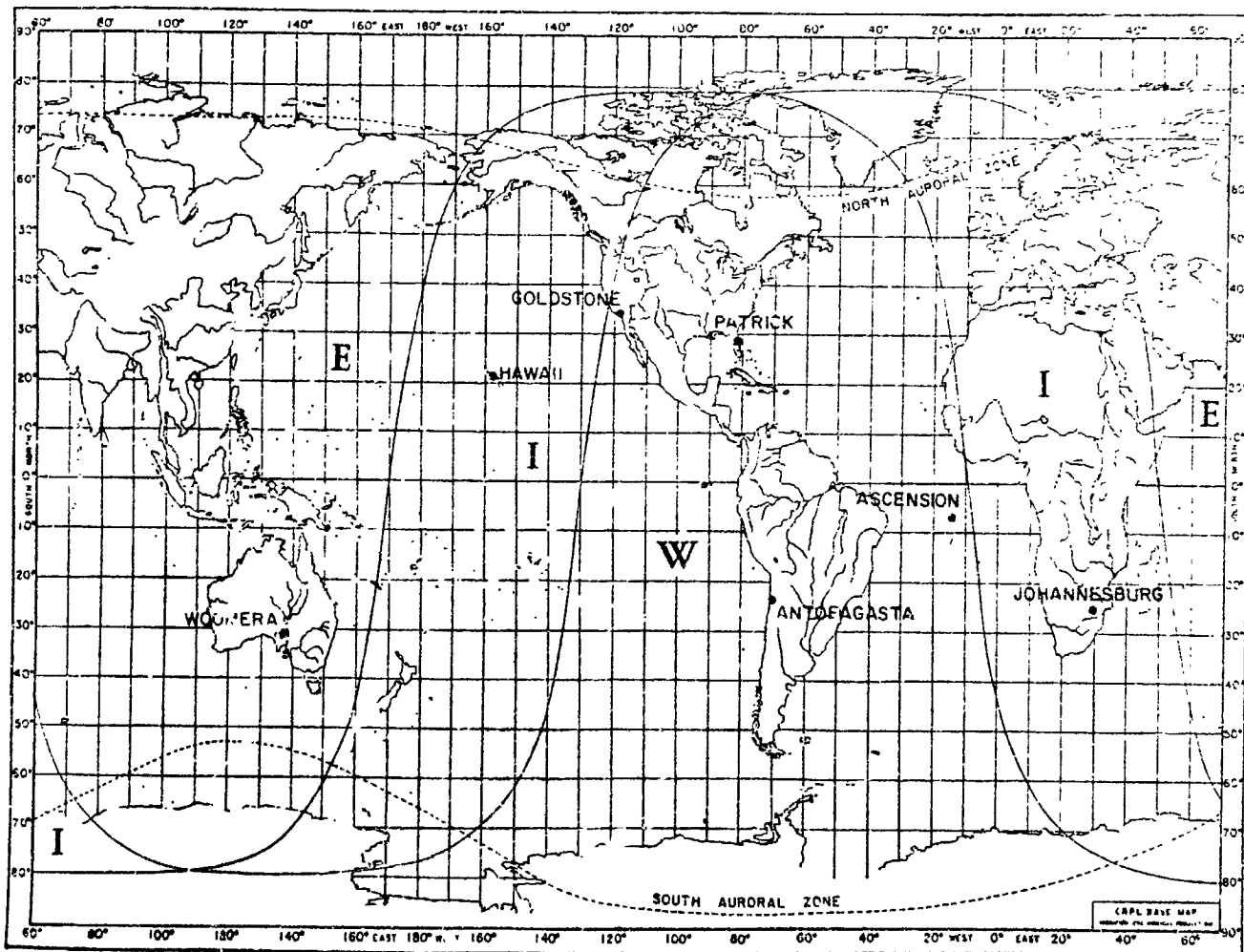
Figure 3-2. World Map Showing DSIF's and Terminal/Relays Studied
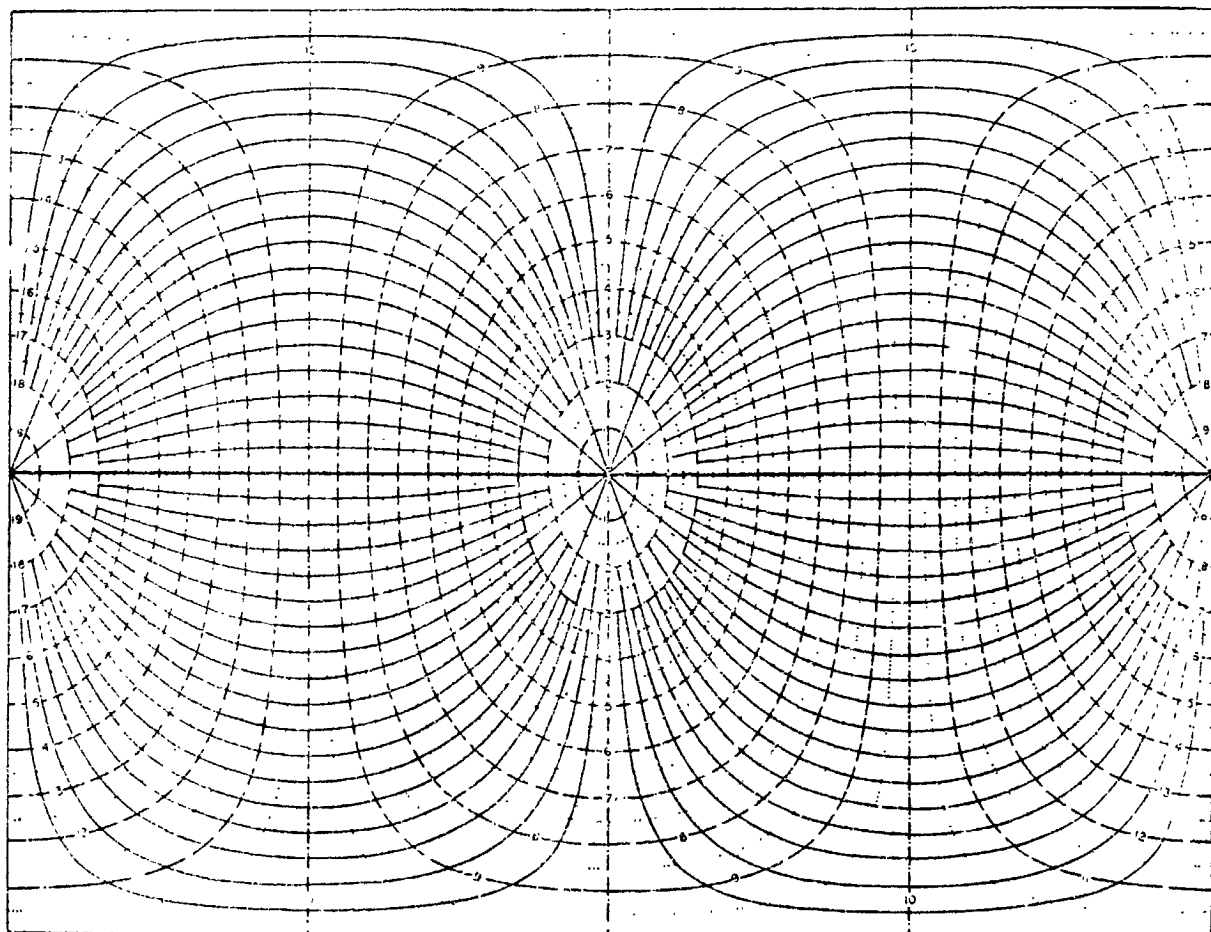
Figure 3-3. Great Circle Chart

DISTANCE IS EXPRESSED IN THOUSANDS OF KILOMETERS
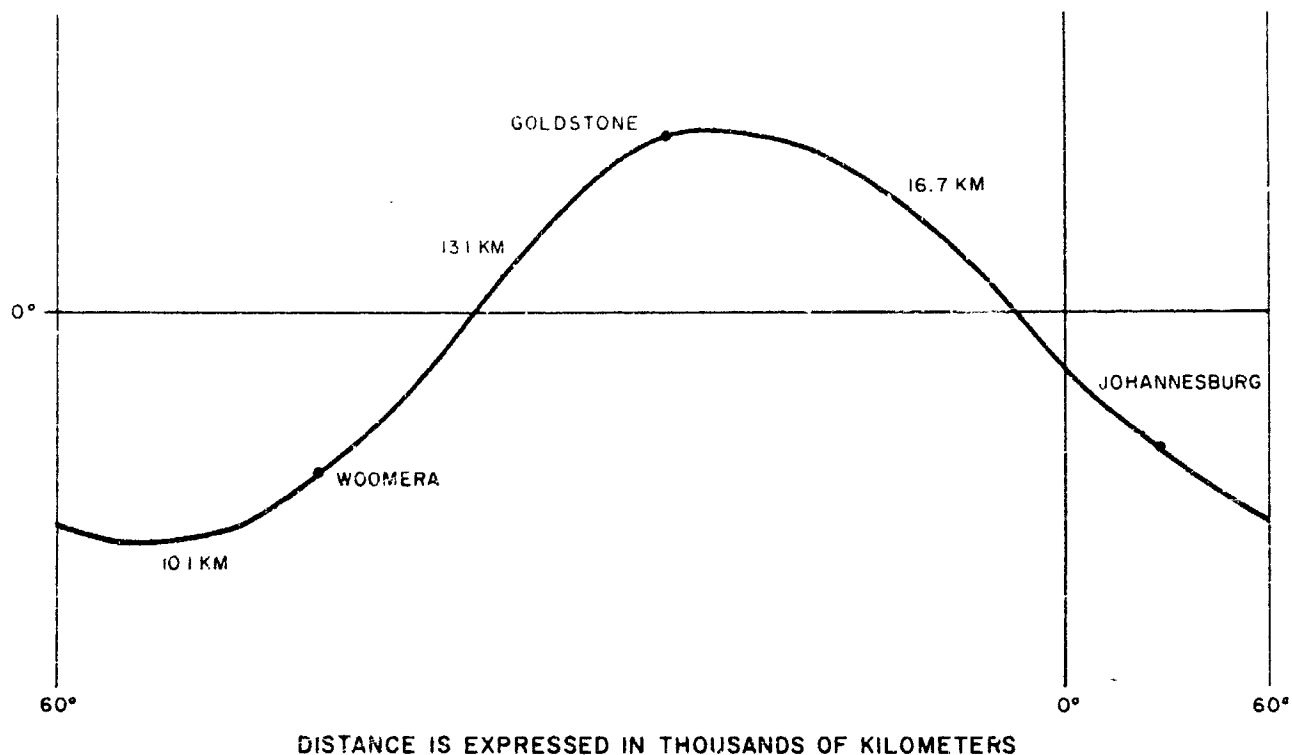
Figure 3-4. Three-Station Complex Great Circle Routes

DISTANCE IS EXPRESSED IN THOUSANDS OF KILOMETERS
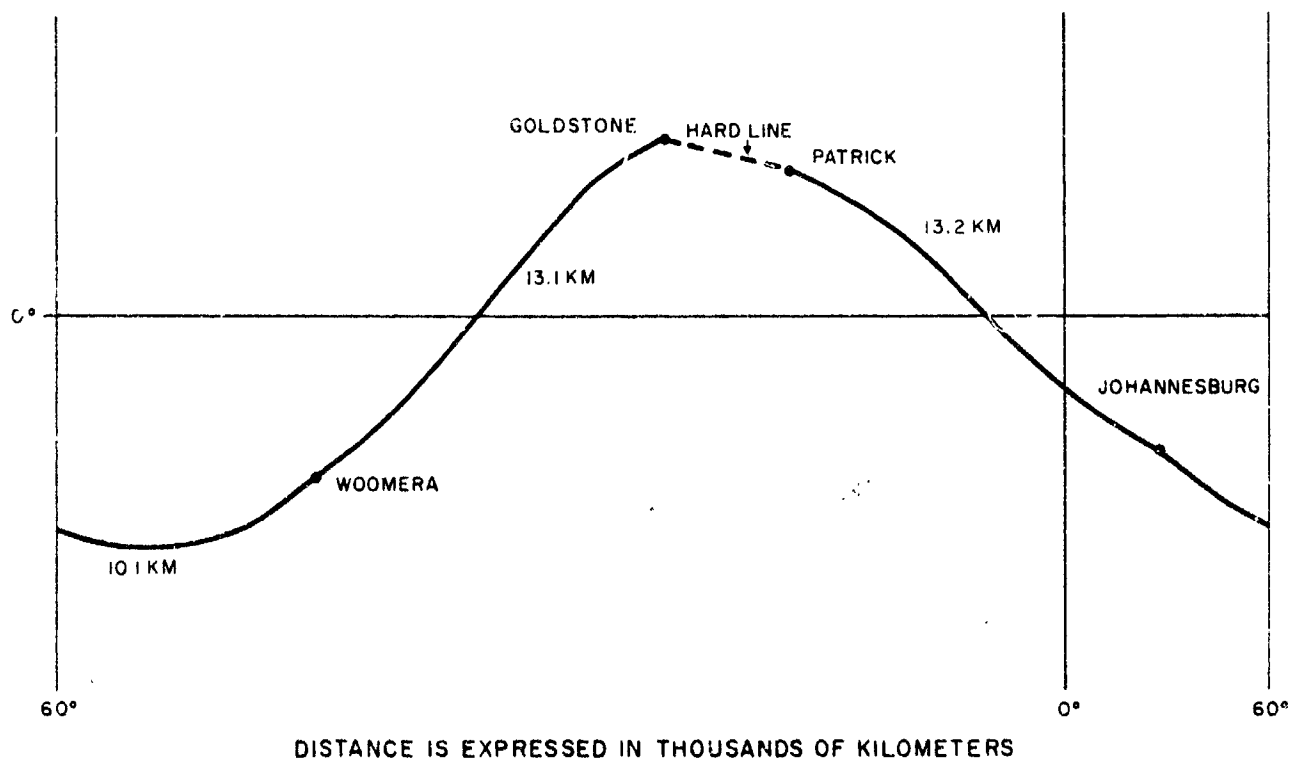
Figure 3-5. Four-Station Complex Great Circle Routes

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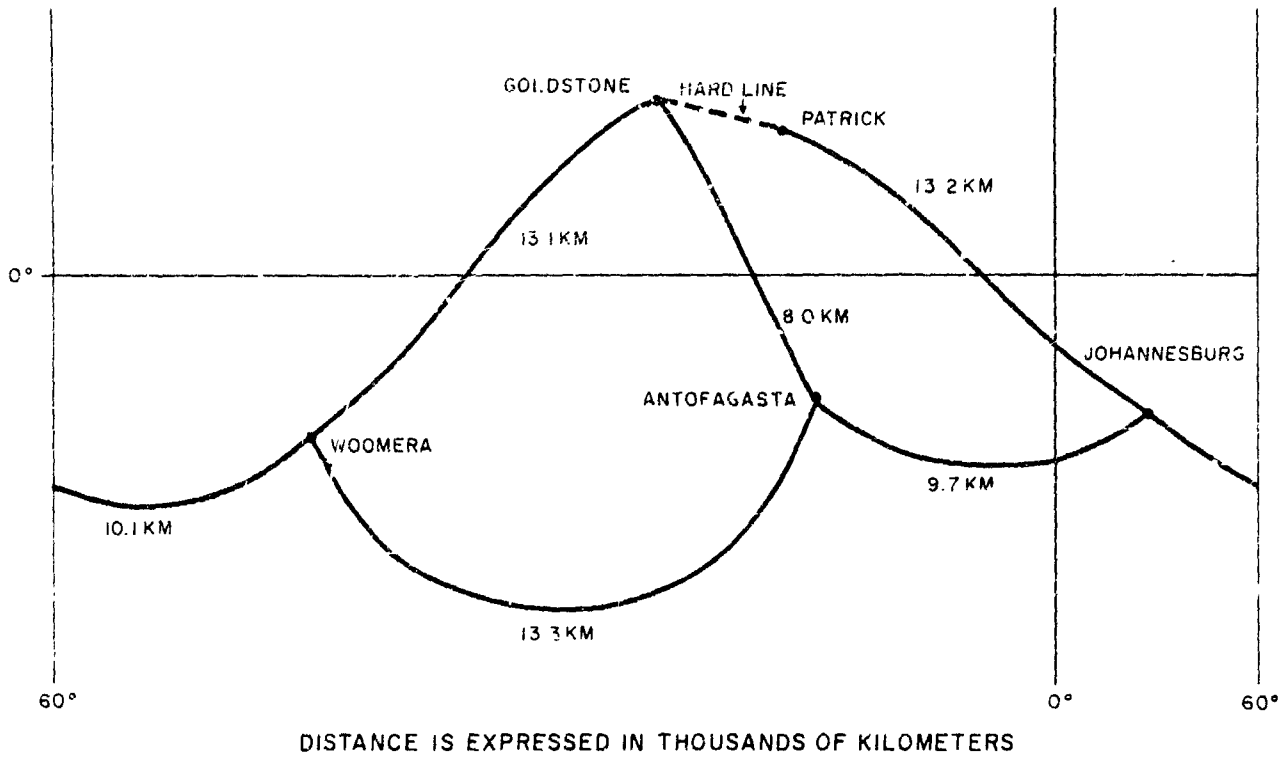
Figure 3-6. Five-Station Complex Great Circle Routes

DISTANCE IS EXPRESSED IN THOUSANDS OF KILOMETERS
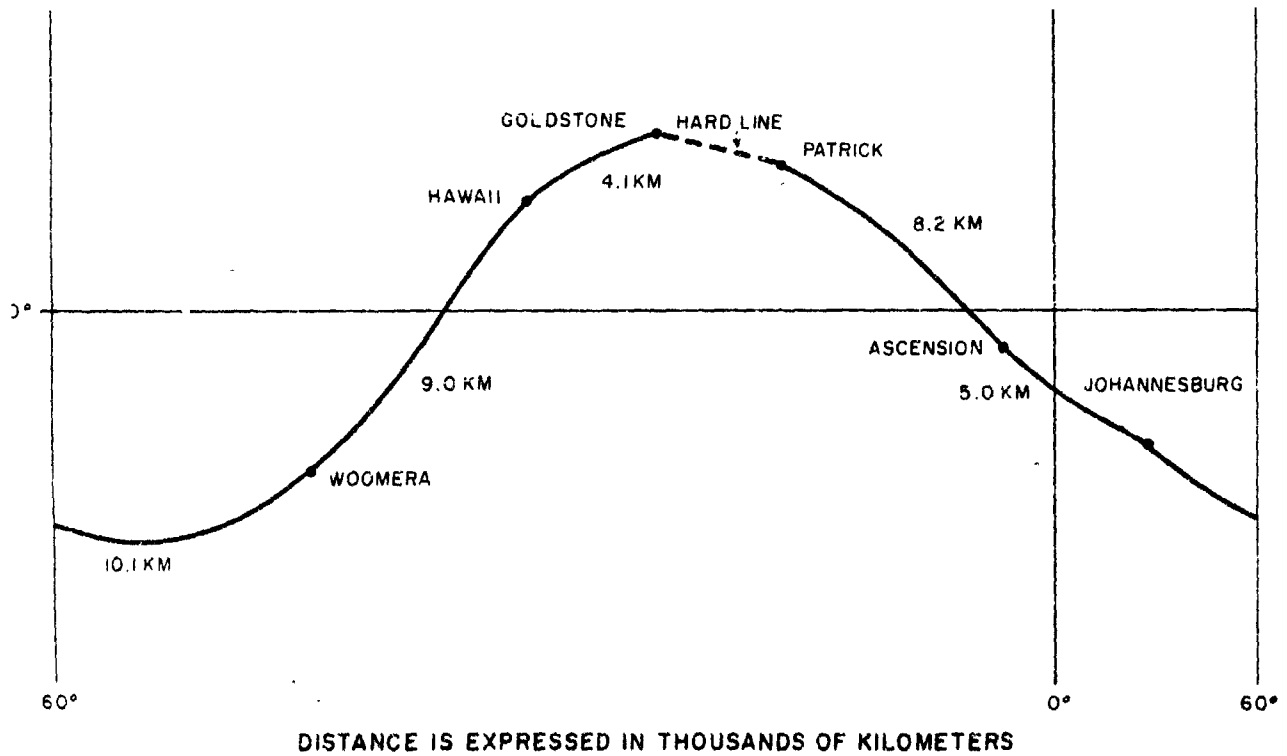
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Figure 3-8. SAMPLE IBM 604 RESULTS

Figure 3-9. Breakdown of Outage Time on the Individual Links
Owing to Nonsupport of Propagation, Six-Station Complex
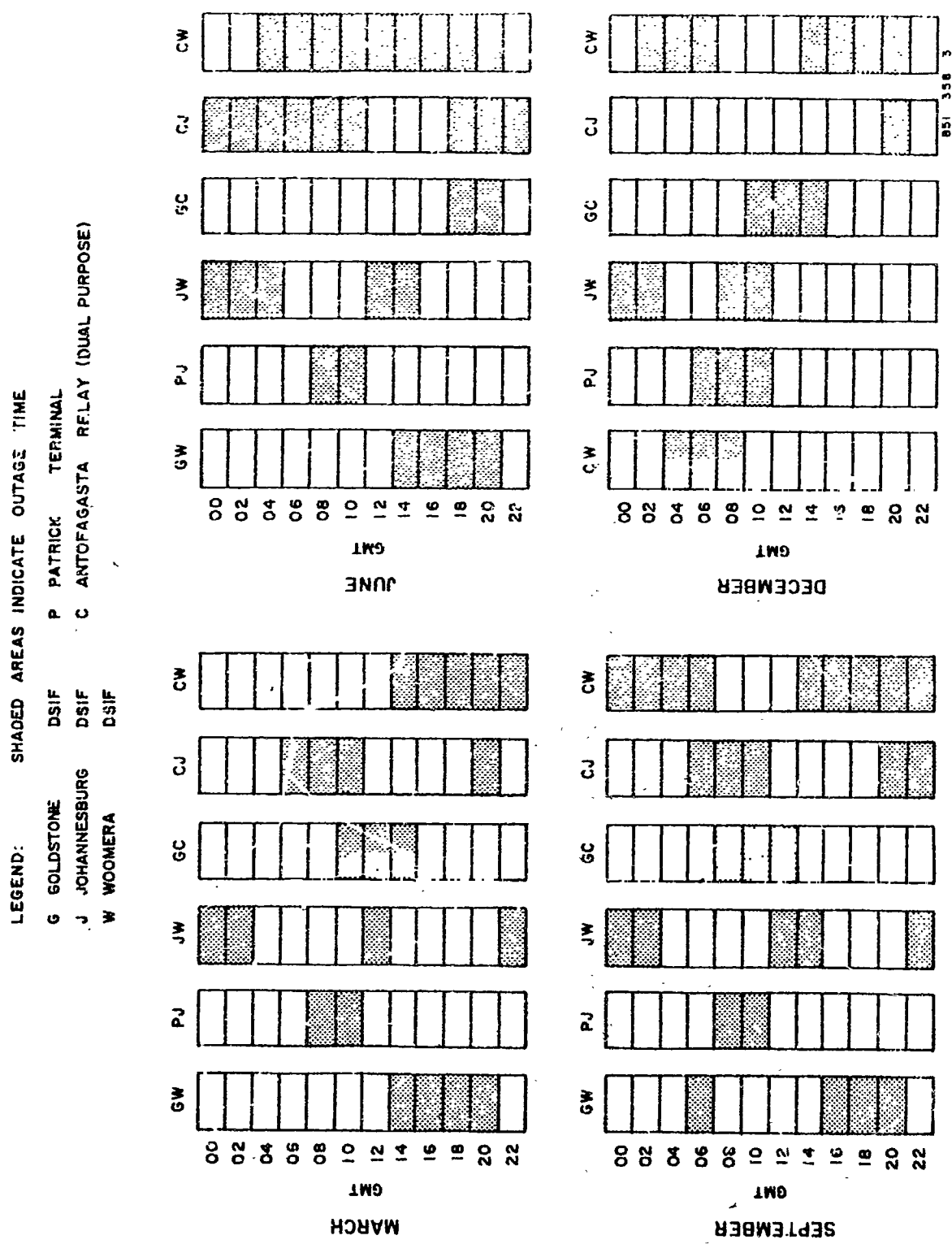
Figure 3-10. Breakdown of Outage Time on the Individual Links
Owing to Nonsupport of Propagation, Five-Station Complex
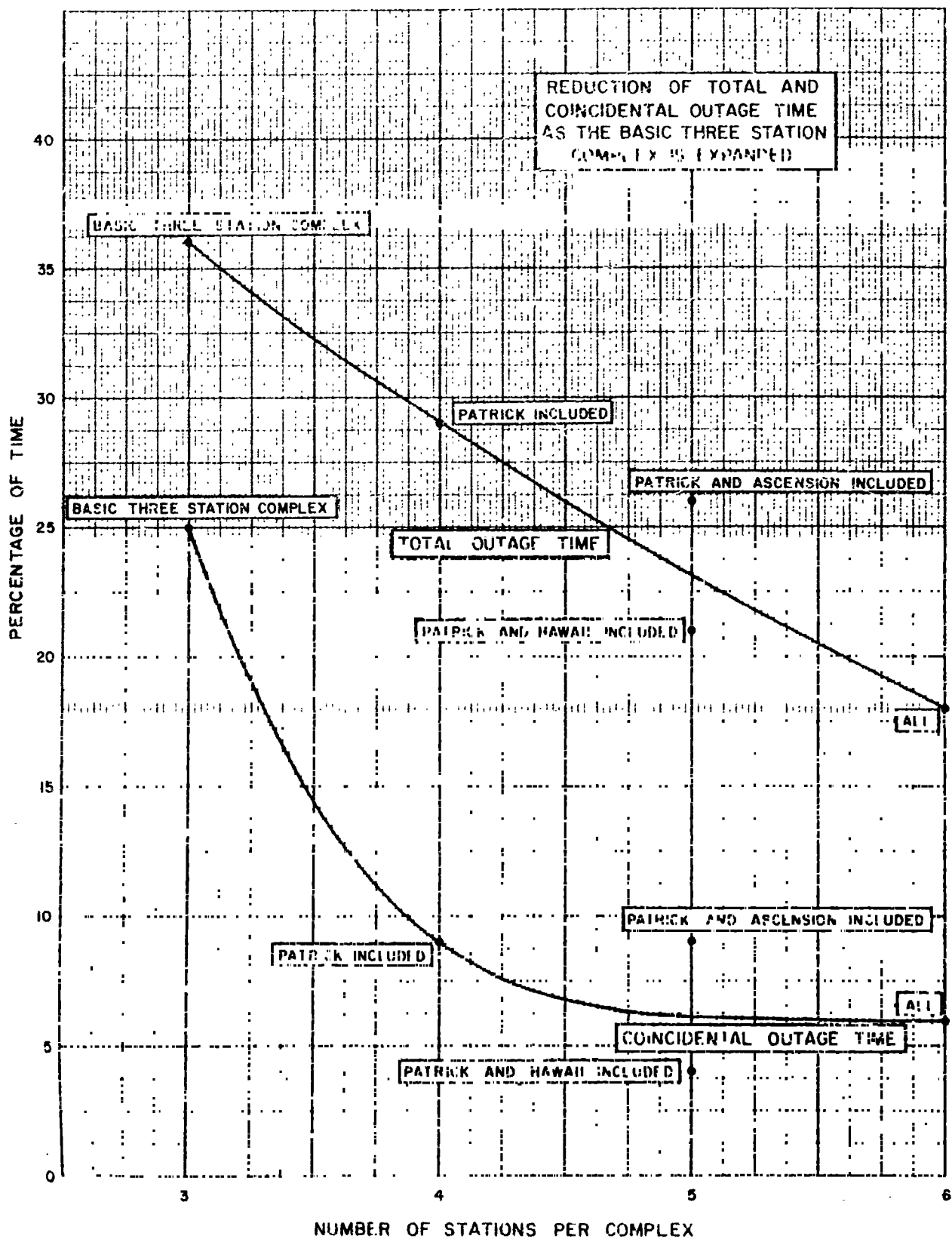
Figure 3-11.   Reduction of Total and Coincidental Outage Time
with Expansion of Basic Complex

RECEIVED SIGNAL STRENGTH IN DB ABOVE 1 uv/m

G Goldstone DSIF
W Woomera DSIF
J Johannesburg DSIF

P Patrick Terminal
H Hawaii Relay
A Ascension Relay

JUNE

GMT	GJ	GW	JW	PJ	HW	PA
00	27	9	37	37	15	43
02	33	13	33	37	19	43
04	33	23	29	37	29	43
06	33	31	27	35	37	43
08	19	37	29	29	43	43
10	3	37	31	19	43	33
12	-7	37	35	11	43	23
14	-1	37	39	5	43	19
16	-1	41	39	11	43	17
18	-5	23	39	21	37	23
20	6	17	39	27	29	31
22	17	11	39	33	17	37

DECEMBER

GMT	GJ	GW	JW	PJ	HW	PA
00	33	9	29	37	15	43
02	33	15	25	37	21	43
04	33	27	19	33	33	43
06	16	29	17	31	33	43
08	13	35	17	25	41	39
10	9	37	23	19	43	35
12	-2	37	27	11	43	27
14	-1	37	33	13	43	25
16	-5	33	37	21	39	25
18	4	27	39	21	33	27
20	18	21	39	31	27	37
22	29	11	35	37	17	43

MARCH

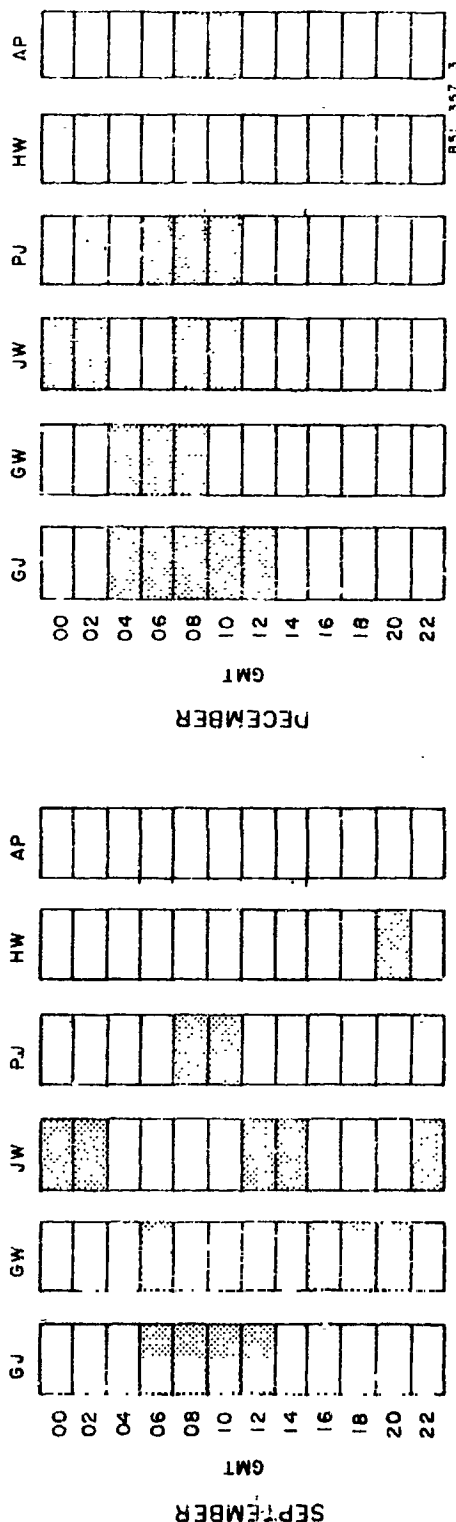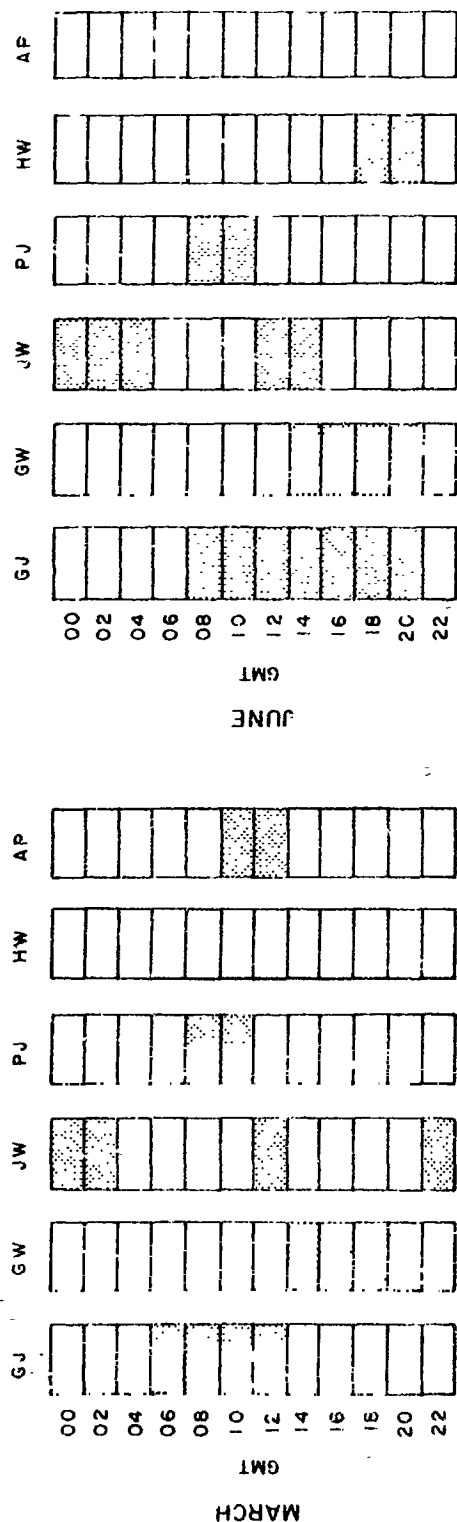| GMT	GJ	GW	JW	PJ	HW	PA
00	31	9	33	37	15	43
02	33	11	29	37	17	43
04	33	27	25	37	33	43
06	29	31	21	33	37	43
08	18	37	21	27	43	43
10	12	37	25	19	43	37
12	-7	37	25	11	43	25
14	-1	37	35	7	43	17
16	-1	33	39	11	39	19
18	2	27	39	21	33	23
20	15	19	39	29	25	33
22	24	11	39	35	17	43

SEPTEMBER

GMT	GJ	GW	JW	PJ	HW	PA
00	31	7	33	37	13	43
02	33	15	29	37	21	43
04	33	23	25	37	29	43
06	29	35	21	33	31	43
08	17	37	23	27	43	43
10	3	37	27	17	43	33
12	-5	37	33	11	43	23
14	-1	37	37	7	43	19
16	-1	31	39	13	37	19
18	2	25	39	21	31	23
20	13	15	39	29	21	35
22	23	9	39	33	15	39

Figure 3-12. Received Signal Strength, All Stations

Figure 3-13. Digital Bandwidth vs Signal-to-Noise for
Two-Element Receiving Antenna
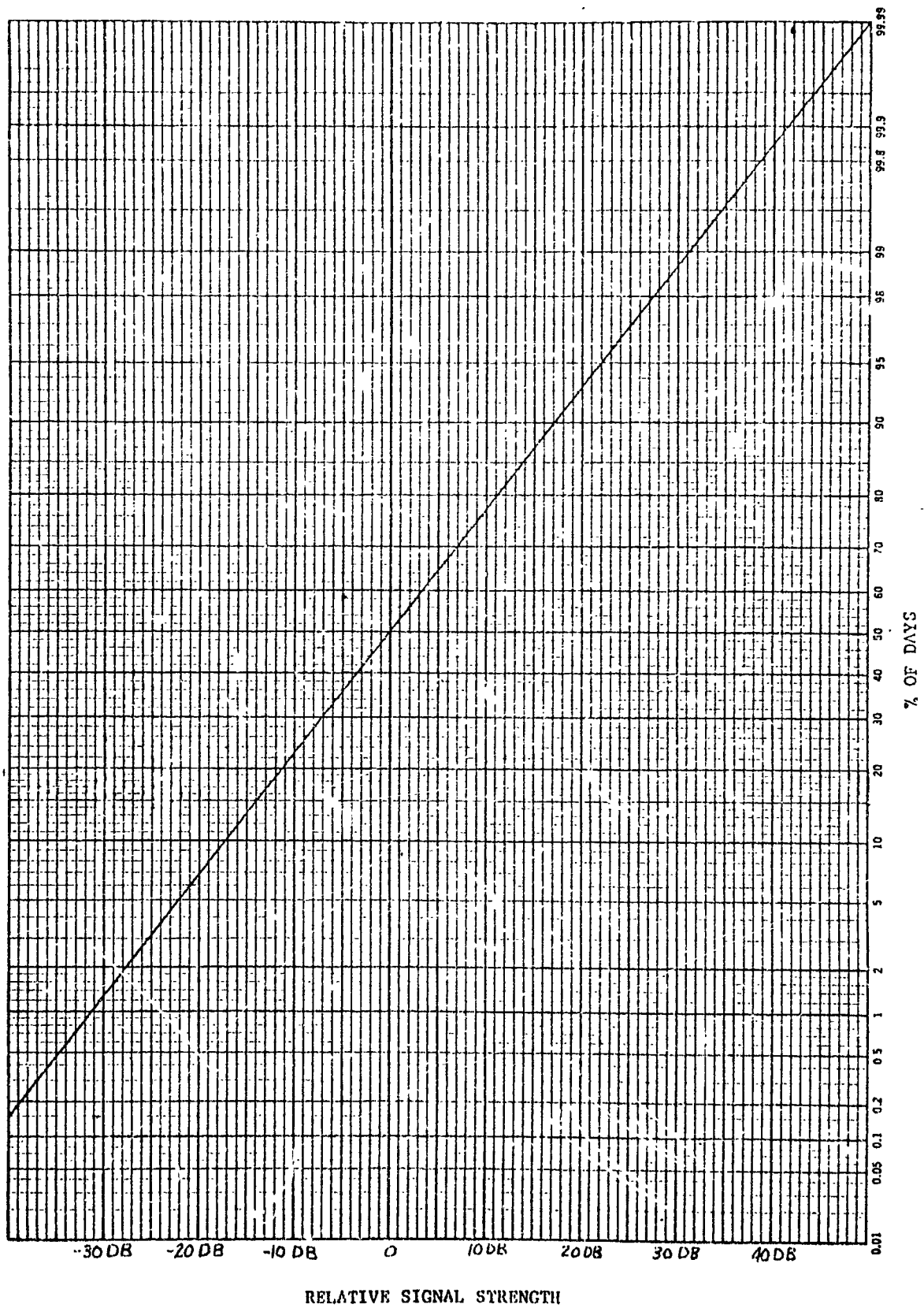
Figure 3-14. Reliability vs Signal Strength

Figure 3-15. Bandwidth vs Communication Reliability
for Digital Coding
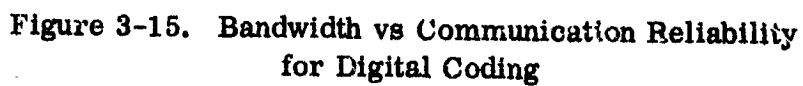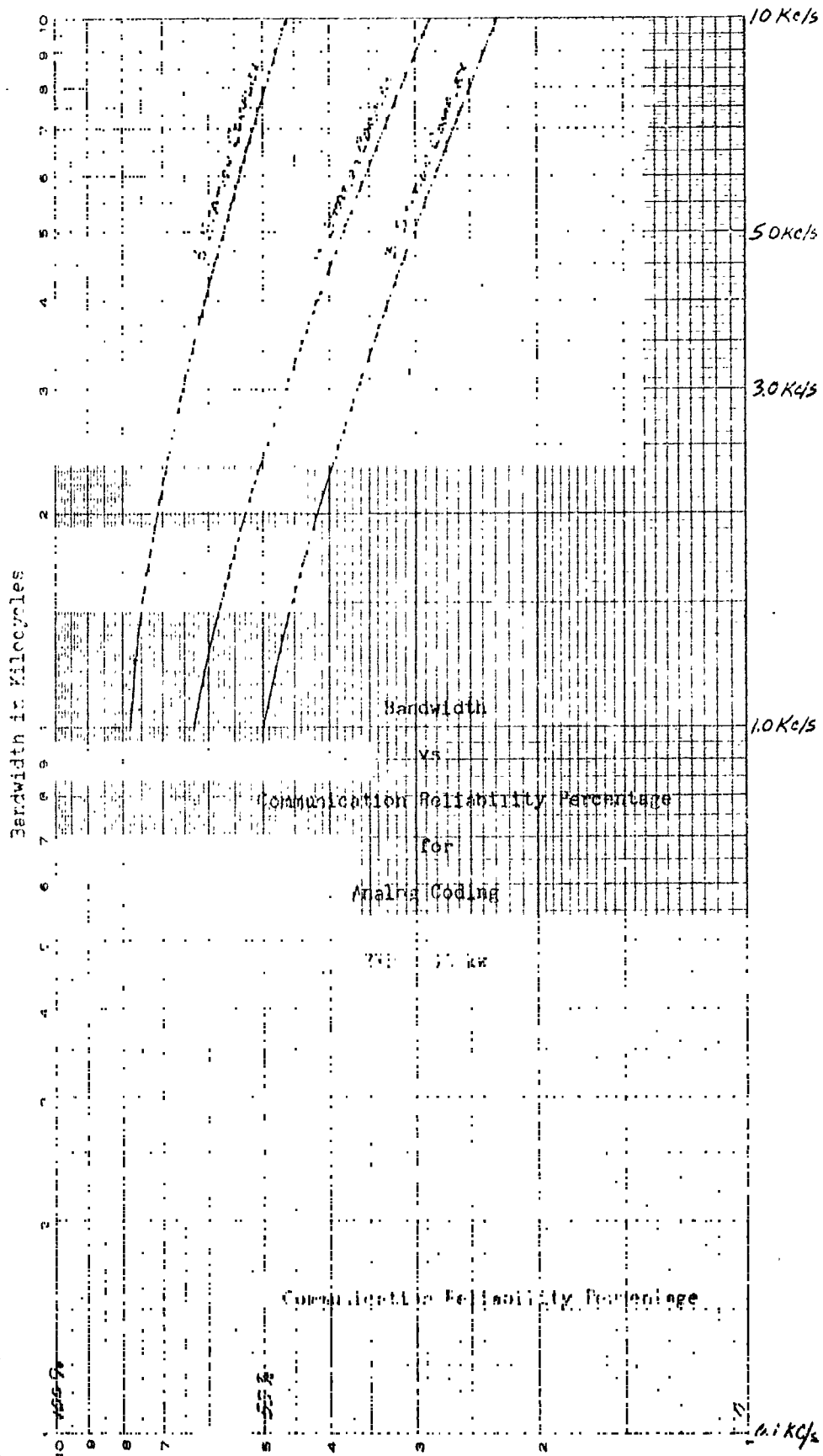
Figure 3-16. Bandwidth vs Communication Reliability
for Analog Coding
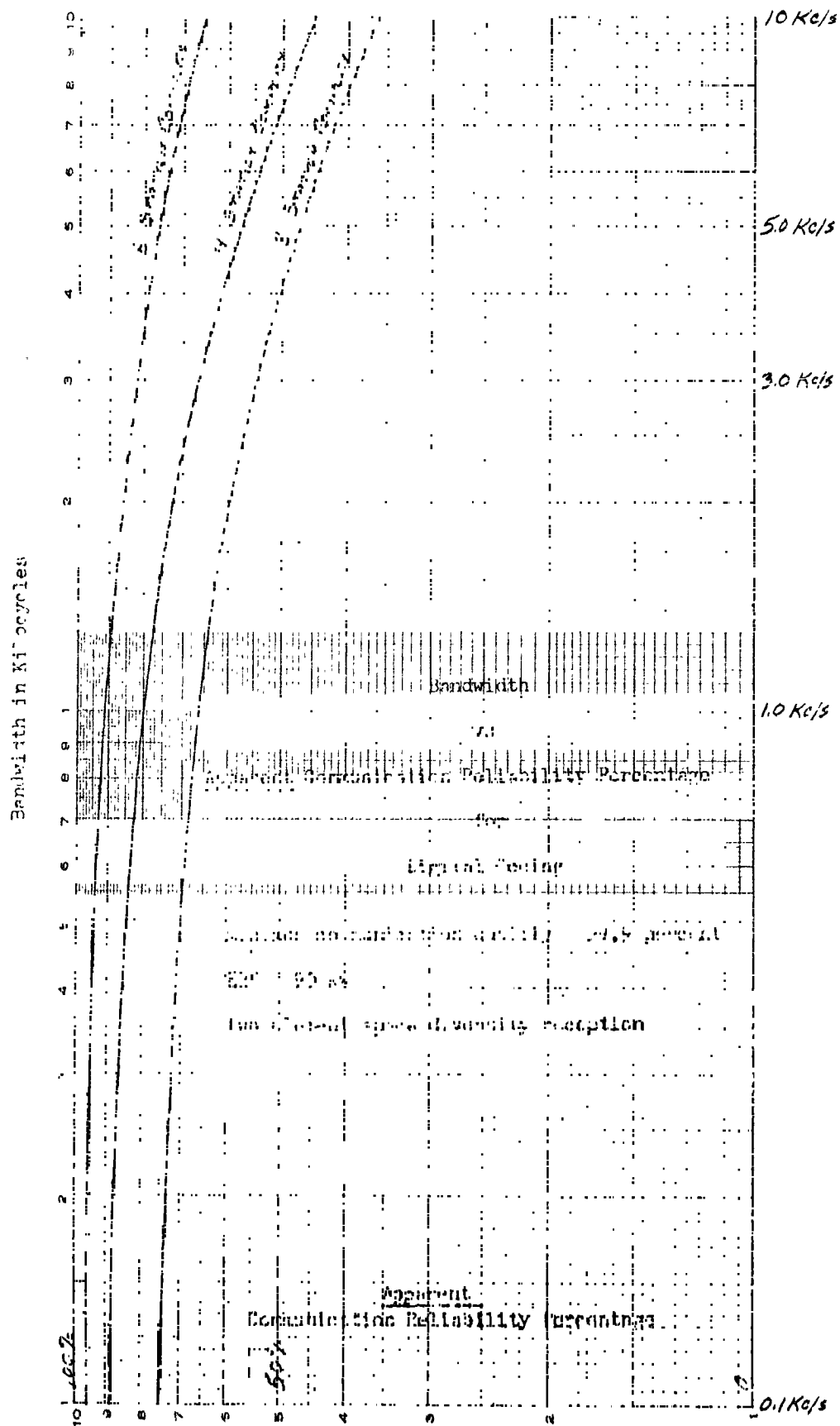
Figure 3-17. Bandwidth vs Apparent Communication
Reliability for Digital Coding
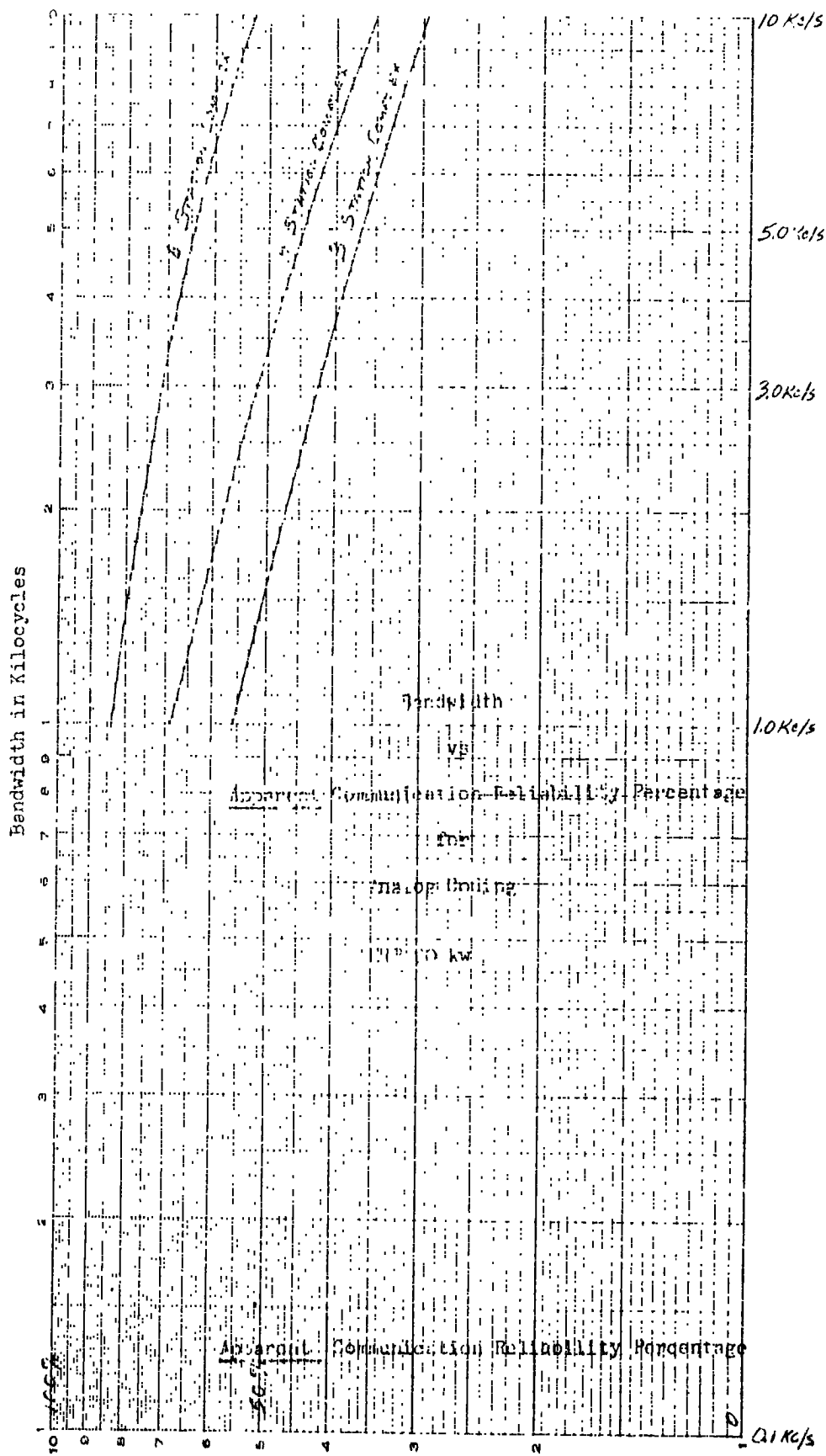
Figure 3-18. Bandwidth vs Apparent Communication
Reliability fo. Analog Coding

Section IV

SERVICES AND EQUIPMENT DESCRIPTIONS

1. LEASED SERVICES.

A survey was made of the services available for leasing from commercial carriers between the locations of the DSIF stations. Two common carriers were outstanding in that they can provide services not offered by any of their competitors. Within the continental limits of the United States, American Telephone and Telegraph can provide a total of six different services, three more than offered by their competition. For international services, RCA Communications Incorporated is the only carrier that can provide direct routes to both Australia and Union of South Africa over its own facilities. Tariffs for either the continental services or the international services are subject to FCC approval, thus the costs for like services are identical irregardless of which common carrier supplies them.

RCA Communication facilities terminate at specific cities in Australia and the Union of South Africa, therefore services have to be leased from local common carriers. The terminal city in Australia is Sydney and services will have to be leased from the Telecommunications Commission of Australia for connection to Woomera. Local service from Woomera to the DSIF site can also be supplied by this organization. The terminal city in the Union of South Africa is Johannesburg. Therefore service from the city to the DSIF site will have to be leased from the Department of Posts and Telegraphs.

a.   AMERICAN TELEPHONE AND TELEGRAPH FACILITIES.

The American Telephone and Telegraph Company can provide 60-, 75-, and 100-word per minute teletype circuits, 3-kc voice circuits, 5-kc data circuits, and 10-kc data circuits within the continental limits of the United States. The costs for these services between different cities in the United States and from Oakland, California to the Hawaiian Islands are shown in table 4-1.

The monthly cost figures for the 5- and 10-kc data circuits are based upon the established tariffs for radio network circuits between the cities shown and are no more than a budgetary cost figure. Before firm quotations can be made for either one of these two types of circuits, the following information must be supplied to AT and T engineering.

1.   The allowable signal-to-noise ratio

2.   The type of signal to be transmitted

3.   The information rate (bits per second) to be transmitted

4.   The allowable frequency delay characteristics

5.   The levels of transmission

6.   The variations in levels of transmission

7.   The permissible outage time

8.   Can the service be released for maintenance

9.   Will the transmission be one way or two way

10.   Will signalling be required for coordination

11.   Will impulse noise be critical

Upon submission of this information, a firm rate will be established and submitted to the FCC for approval. A minimum time interval of ninety days will be

required before the service is available. All other services offered by this company are available within a period of fourteen days from receipt of orders.

b.   RCA COMMUNICATIONS, INCORPORATED FACILITIES

RCA Communications, Incorporated, can provide 60 word per minute teletype circuits, 60 or 100 words per minute teletype circuits equipped with ARQ, 180 bits per second rate data circuits, and facsimile circuits between New York City and Madrid, Spain or Johannesburg, Union of South Africa and between San Francisco and Sydney, Australia on a continuous basis. The costs for these services are shown in table 4-2. Reliabilities of 96 percent for these circuits have been quoted by RCA Communications. However, the percent reliability is an average of the reliabilities over the past eight months, a period when high frequency propagation has been exceedingly good. For long range reliability, the services offered by RCA can be no better than those of a privately-owned facility because the circuit reliability of both are dependent upon the vagaries of high frequency propagation. Under ordinary circumstances and depending upon the type circuit ordered, the circuits are available within a period of fourteen to sixty days from receipt of order.

c.   ALL AMERICA CABLES AND RADIO FACILITIES.

The All America Cables and Radio Company can provide 60 or 100 words per minute teletype circuits and data processing circuits (no information rate supplied) between New York City and Madrid, Spain. This company will not normally quote on services to Australia or Union of South Africa because they cannot provide direct communications. However they recommend using RCA Communications, Incorporated, facilities for communicating with these two countries. The costs for the services to Madrid via this carrier are shown in table 4-3.

d.   TELECOMMUNICATIONS COMMISSION OF AUSTRALIA FACILITIES.

The Telecommunication Commission of Australia can provide the same

facilities as offered by RCA Communications, Incorporated. The costs for the

different categories are shown in table 4-4 for circuits between Sydney and Woomera,

Australia. Orders for the required service can be placed with RCA Communications

and will be available concurrent with same service from RCA. Localized service

from Woomera to the DSIF station location has not been included in this study because

the exact location of the station with respect to Woomera is unknown.

e.   DEPARTMENT OF POSTS AND TELEGRAPHS-UNION OF SOUTH AFRICA.

The Department of Posts and Telegraphs can provide the same facilities between

Johannesburg and the DSIF station location as offered by RCA Communications,

Incorporated, between New York City and Johannesburg. Orders for the required

service can be placed with RCA Communications and will be available concurrently

with the same service from RCA. These costs have not been included as part of this

study because the exact location of the DSIF station with respect to Johannesburg is

unknown.

2.   PRIVATELY OWNED FACILITIES.

A number of different communication complexes were investigated as discussed

in Section III. The first to be investigated was a three-station complex with communi-

cation stations located at each of the DSIF station locations. When the investigation

indicated that the reliabilities of a three-station complex were low for the higher data

rates and wider bandwidths, a fourth station located near Patrick Air Force Base,

Florida was added. This four-station communication complex would utilize the station

near PAFB as a relay on the Goldstone-Johannesburg link and would be connected to the

Goldstone facilities via leased wire lines. A five-station communication complex utilizing a shared relay station located near Antofagasta, Chile was also investigated, but propagation conditions between Chile and Australia or the Union of South Africa were so poor that this complex was eliminated early in the study. A six-station communication complex made of the four-station complex plus a relay station located in the Hawaiian Islands and a relay station located on Ascension Island was the last complex to be investigated.

a. THREE-STATION COMMUNICATION COMPLEX.

The three-station communication complex has a communication station located at each of the DSIF station locations. The stateside station located at the Goldstone DSIF site would be equipped with the following major equipments:

2 single side band exciters (one for back-up)

3 single side band receivers (one for back-up)

2 10-kw linear amplifiers (one for back-up)

1 set of terminal equipments (type to be compatible with the communication option selected)

3 rotatable broad-band antennas

2 100-kw diesel generators (one for back-up)

For the analog channel options, two frequency modulated exciters would be substituted for the single side band exciters and a fm detector module would be supplied as part of the single sideband receivers.

The communication stations located near the Woomera and Johannesburg DSIF stations would be equipped to serve as relay stations. This permits either the Woomera or Johannesburg station to relay information through each other when direct communication to the Goldstone station is impossible. Major equipments to be installed at these two stations are as follows:

3 single sideband exciters (one for back-up)

5 single sideband receivers (one for back-up)

3 10-kw linear amplifiers (one for back-up)

2 sets of terminal equipments (type to be compatible with the communication option selected)

6 broadband antennas

2 100-kw diesel generators (one for back-up)

For the analog channel options, three frequency-modulated exciters would be substituted for the single sideband exciters a fm detector module would be supplied as part of the single sideband receivers. Initial and operating costs for the three station complex are tabulated in Section V of this report.

b.   FOUR-STATION COMMUNICATION COMPLEX.

The four-station communication complex has a communication station located at each of the DSIF station locations plus a relay station located in the vicinity of Patrick Air Force Base, Florida. The station located near PAFB is to be connected to the Goldstone facility by leased wire lines. Terminal equipment included as part of this station could be installed at the Goldstone site, thus eliminating the need for additional terminal equipment for the cross-country wire line facility. Both of the stateside stations would be equipped with the following major equipments:

2 single sideband exciters (one for back-up)

3 single sideband receivers (one for back-up)

2 10-kw linear amplifiers (one for back-up)

1 set of terminal equipments (type to be compatible with the communications option selected)

3 broadband antennas

2 100-kw diesel generators (one for back-up)

ᵣor the analog channels options, two frequency modulated exciters would be substituted for the single sideband exciters and an fm detector module would be supplied as part of the single sideband receivers.

The communication stations located near the Woomera and Johannesburg DSIF stations would again be equipped to serve as relay stations for the same reason as detailed in the discussion of the three station communication complex. Major equipments to be installed at these two stations are as follows:

3 single sideband exciters (one for back-up)

5 single sideband receivers (one for back-up)

3 10-kw linear amplifiers (one for back-up)

2 sets of terminal equipment (type to be compatible with the communications option selected)

6 broad band antennas

2 100-kw diesel generators (one for back-up)

For the analog channel options, three frequency modulated exciters would be substituted for the single sideband exciters and a fm detector module would be supplied as part of the single sideband receivers. Initial and operating costs for the three station complex are tabulated in Section V of this report.

c.   FIVE-STATION COMMUNICATION COMPLEX.

A five-station communication complex consisting of the four stations plus a dual-purpose relay located near Antofagasta, Chile, was investigated. The propagation study indicated that the Chilean location for the dual-purpose relay location was

poor and the length of time allocated for this report did not permit further exploration for additional site locations for a dual-purpose relay station.

d. SIX-STATION COMMUNICATION COMPLEX.

The six-station communication complex has a communication station located at each of the DSIF station locations plus three relay stations, one in the vicinity of Patrick Air Force Base, one in the Hawaiian Islands, and one on Ascension Island. The relay station located near PAFB would be connected to the Goldstone facility by leased wire lines. Terminal equipment included as part of this station could be installed at the Goldstone facility thus eliminating the need for additional terminal equipment for the cross-country wire line facility. Both of the stateside stations would be equipped with the following major equipments:

2 single sideband exciters (one for back-up)

3 single sideband receivers (one for back-up)

2 10-kw linear amplifiers (one for back-up)

1 set of terminal equipments (type to be compatible with the communications option selected)

3 broadband antennas

2 100-kw diesel generators (one for back-up)

For the analog channel options, two frequency modulated exciters would be substituted for the single sideband exciters and a fm detector module would be supplied as part of the single sideband receivers.

The communication stations located near the Woomera and Johannesburg DSIF station locations and the relay stations located in the Hawaiian Islands and on Ascension Island would be identical in major equipment complement. This complement consists of:

3 single sideband exciters (one for back-up)

5 single sideband receivers (one for back-up)

3 10-kw linear amplifiers (one for back-up)

2 sets of terminal equipments (type to be compatible with communications option selected)

6 broadband antennas

2 100-kw diesel generators (onw for back-up)

For the analog channel options, three frequency modulated exciters would be substituted for the single sideband exciters and a f, detector module would be supplied as part of the single sideband receivers. Initial and operating costs for the six-station complex are tabulated in Section V of this report.

e.   EQUIPMENT DESCRIPTIONS.

In order to completely define the areas covered by this study, a brief descriptive specification of the equipments to be utilized in the privately owned facilities has been included in this report.

(1) SINGLE SIDEBAND EXCITERS. The exciters used in this study for the transmission of digital data and voice communication options are manually-tuned, high-frequency, rack-mounted exciters. They provide selection of 28,000 channels spaced at intervals of 1 kc in the range of 2.0 to 30.0 mc. The exciters are available in either 3-kc or 6-kc bandwidths on either sideband. A selector switch provides the means for switching the outputs for upper sideband, lower sideband, independent sideband or amplitude modulated emissions. The exciters are used with a high-stability oscillator which provides a frequency stability of one part in 10^8 per day or better, thus eliminating the need of transmitting a pilot carrier. Operating frequency is

indicated upon a direct reading dial and frequency selection is controlled by two controls, a bandswitch selector that permits selection of one of the four bands of frequencies and the dial control that selects the operating frequency in the particular band.

(2) FREQUENCY MODULATED EXCITER. The exciters used in this study for the transmission of analog data are manually-tuned, high-frequency, rack-mounted exciters. They provide excitation frequencies in the range of 2.0 to 30.0 mc. The exciters contain a variable frequency deviation control permitting excitation at bandwidths of 1, 3, 5 or 10 kilocycles. The response of the audio sections is within 1 db over a frequency range of 1/15 of a cycle to 10-kc.

(3) RECEIVERS. The receivers used in this study for receiving all types of data or voice transmissions are manually tuned high-frequency rack mounted receivers. They provide selection of 28,000 channels spaced at intervals of 1 kc in the range of 2.0 to 30.0 mc. The receivers are available in either 3-kc or 6-kc bandwidths on either sideband. A selector switch provides the means for switching to receive emissions on upper sideband, lower sideband, or independent sideband, and amplitude modulated or frequency modulated emissions. The receiver is used with a high-stability oscillator which provides a frequency stability of one part in 10^8 per day or better. Operating frequency is indicated upon a direct reading dial and frequency selection is controlled by two controls, a bandswitch selector that permits selection of one of the four bands of frequencies and the dial control that selects the operating frequency in the particular band.

(4) LINEAR AMPLIFIER. The linear amplifier used in this study is a 10-kc peak envelope power amplifier. Although it has been specifically designed for high

performance single sideband service, it is equally capable of amplifying any type of signal having an r-f power of 0.1 watts and a bandwidth of no more than 16 kc to the 10-kc PEP level. It is a manually tuned equipment, but phase detectors provide an accurate indication of resonance on a zero-center meter. Dial settings can be accurately logged for relative quick channel changing. The amplifier contains its own integral power supply and requires a mounting area of only 3-1/2 square feet of floor space.

(5) TERMINAL EQUIPMENT. The digital data terminal equipment used in this study is an efficient, high-speed, high-capacity data terminal. It is highly flexible and can be tailored to fit any particular requirement. Basically, it consists of modular units each of which provide a bit rate capability of 75 bits per second. Thus, if a bit rate capability of 1050 bits per second is required, fourteen separate modular units will provide this capability. The equipment features a diversity phase-shifte system using predicted wave signalling techniques that are required for the signal quality of .001 binary error rate used in this study. The module mounting plates fit any standard 19-inch relay rack.

(6) ANTENNAS. The antennas used in this study are compact wideband antennas that require a minimum of real estate. They have the following features:

a. Essentially constant impedance and good radiation pattern over a band from 6.5 to 60.0 mc

b. Elimination of the need of using several structures in an antenna installation to cover the full range of frequencies

c. Performance comparable to a four-element yagi but over an extremely wide frequency range

d. Flexibility of operation, with the antenna mounted on a rotatable mast to provide 360° azimuthal coverage where required

e. Rugged construction to withstand severe environmental conditions for long life and reliable performance

f. Erection can be made rapidly without the need of heavy equipment

g. Maximum real estate requirements are only 12,100 square feet including guy wires. The base of the antenna only requires a 7 foot by 5 foot mounting area

Table 4-1. Costs of Services Offered by American Telephone & Telegraph Company

Circuit	60 WPM Manual Machine		60 WPM Automatic Machine		75 WPM Automatic Machine		100 WPM Automatic Machine	
	Inst. Cost	Monthly Cost	Inst. Cost	Monthly Cost	Inst. Cost	Monthly Cost	Inst. Cost	Monthly Cost
Pasadena to New York	$50	$2700.83	$50	$2790.83	$50	$3049.91	$50	$5448.54
Pasadena to Miami, Fla.	$50	$2628.18	$50	$2718.18	$50	$2969.99	$50	$3142.73
Pasadena to Oakland, Cal.	$50	$609.78	$50	$699.78	$50	$749.76	$50	$834.73
Oakland Cal. to Hawaii			$50	$7000	$50	$7700	$50	$8750

Table 4-1. Costs of Services Offered by American Telephone & Telegraph Company (continued)

Circuit	Voice		5KC BW DATA		10KC BW DATA	
	Inst. Cost	Monthly Cost	Inst. Cost	Monthly Cost	Inst. Cost	Monthly Cost
Pasadena to New York	$20	$3425.70	$50	$16,847.70	$50	$26,278.30
Pasadena to Miami, Fla.	$20	$3325.95	$50	$16,201.70	$50	$27,866.80
Pasadena to Oakland, Cal.	$20	$ 780.90	Not Established		Not Established	
Oakland, Cal. to Hawaii	$20	$20,000	Not Established		Not Established	

Table 4-2. Costs of Services Offered by RCA Communications, Inc.

Costs per Channel

Circuit	60 WPM Teletype		60 WPM Teletype with ARQ		100 WPM Teletype with ARQ		Data 180 bits/sec.		Facsimile	
	Inst. Cost	Monthly Cost	Inst. Cost	Monthly Cost	Inst. Cost	Monthly Cost	Inst. Cost	Monthly Cost	Inst. Cost	Monthly Cost
New York to Madrid	$250	$8,000	$250	$8,710	$250	$12,000	$250	$14,000	$250	$16,000
New York to Johannesburg		$8,000		$8,710		$12,000		$14,000		$16,000
San Francisco to Sydney		$8,752		$9,107		$12,547		$14,638		$16,752

Table 4-3. Costs of Services Offered by All America Cables and Radio

Circuit	Costs per Channel					
	60 WPM Teletype		100 WPM Teletype		Data Processing	
	Inst. Cost	Monthly Cost	Inst. Cost	Monthly Cost	Inst. Cost	Monthly Cost
New York to Madrid	$250	$8000	$250	$12,000	$250	$15,000 to 16,000

Table 4-4. Costs of Services Offered by Telecommunication Commission of Australia

Circuit	Costs per Channel							
	60 WPM Tele-type with ARQ		100 WPM Tele-type with ARQ		Data 180 bits/sec.		Facsimile	
	Inst. Cost	Monthly Cost	Inst. Cost	Monthly Cost	Inst. Cost	Monthly Cost	Inst. Cost	Monthly Cost
Sydney to Woomera	Not Avail.	$2,325	Not Avail.	$3,240	Not Avail.	$3,870	Not Avail.	$4,320

Section V

COSTS

1. LEASED SERVICES.

The budgetary cost figures for leased services for twx channels interconnecting the three Deep Space Instrument Facility Stations and having a reliability of at least 60 per cent are shown in figure 5-1, which also indicates the routing required. The costs shown are for one twx channel to the terminating cities of Woomera and Johannesburg and do not include the costs for services from these cities to the DSIF stations sites because their locations are unknown.

2. PRIVATE FACILITIES COSTS.

a. FIXED COSTS.

The fixed costs for the privately owned facilities are made up of equipment costs, building and facilities cost, installation costs, and shipping charges.

The budgetary equipment costs shown in figures 5-2 through 5-4 include the costs of the major equipments, custom-built equipments required for specific locations, back-up equipments, spare parts, and the systems engineering costs necessary to define the system design, to prepare specification, to prepare test procedures, to prepare bills of materials, and the system engineering effort necessary to provide an efficient and reliable communication system. For each system shown the costs provide for full-duplex facilities, space diversity reception, and power generating equipment.

The building and facilities costs shown are budgetary estimates for construction of one 400 square foot building from local materials, the necessary water and sewage facilities, heating. and air conditioning. In making these estimates, it has been assumed that all radio equipments would be located at a single site, thus one building and one set of facilities will be sufficient. It has also been assumed that the geology of the sites selected are such that a water supply is readily available for drilling and that a septic tank sewage system will function properly. Costs of real estate procurement, construction of access roads, and a building to house the power generating equipment have not been included.

The budgetary installation costs shown provide for complete installation and testing of all the sites contained in each complex. This includes installation of all antennas and equipments, burial of coaxial cable, and the installation of leased wire lines for the complexes requiring them. It has been assumed that billeting and messing facilities as well as local transportation will be available to the installation personnel at all sites.

The budgetary packaging and shipping charges include the costs of packaging the equipment for shipment to all sites and the shipping charges to those sites. Export packaging is to be supplied for only those equipments whose destination is overseas. It has been assumed that the type of carriers used will be motor freight and ocean going vessels.

b. OPERATING COSTS.

The budgetary operating costs shown in figures 5-2 through 5-4 include the costs of operating the power generating equipment, of leasing the wire lines from

Patrick Air Force Base to Goldstone for the four-and six-station complex, and of

providing a crew of operators for each station to insure 24 hour-a-day, 7 days-per-

week operation. A total of four two-man crews plus a supervisor has been considered

to be adequate for operation of any station. It has been assumed that fuel for the

diesel generator is readily available, and that messing and billeting facilities as

well as local transportation is available for use of the operating personnel.

c. THREE-STATION COMMUNICATION COMPLEX COSTS.

Figure 5-2 is a tabulation of the total fixed costs and the operating costs for a

three-station communications complex for ten different types of services. This

complex has stations located at each of the DSIF station sites, Goldstone, Woomera,

and Johannesburg. Attention is called to the absence of any cost figures for two TWX

lines and two 5-kc analog channels. It is impossible to provide this service on one

set of radio equipments when the response of the analog channels are required to be

within one db over a frequency range of one-fifteenth of a cycle to five kilocycles.

It would require three different sets of equipments to provide this service simultane-

ously. Therefore, the costs were considered to be too great to be included. These

costs have also been omitted from the four-and six-station communication complexes.

The costs versus information rate capability for the three station complex are

diagramed graphically in figures 5-5, 5-6, and 5-7.

d. FOUR-STATION COMMUNICATION COMPLEX COSTS.

Figure 6-3 is a tabulation of the total fixed costs and operating costs for a

four-station communications complex for ten different types of services. This

complex has stations located at each of the DSIF station sites plus a relay station

located near Patrick Air Force Base, Florida. The relay station is connected to the

Goldstone facility by leased wire lines and the monthly charges for this service has been included in the total operating costs per month. No costs appear for the two twx lines and two 5-kc analog channels for the reasons discussed in paragraph c. The costs versus information rate capability for the four station complex has been diagrammed graphically in figures 5-5, 5-6, and 5-7.

    e.   SIX-STATION COMMUNICATION COMPLEX COSTS

Figure 6-4 is a tabulation of the total fixed costs and operating costs for a four-station communications complex for ten different types of services. This complex has stations located at each of the DSIF station sites plus a relay station located near Patrick Air Force Base, Florida, one located in the Hawaiian Islands, and one located on Ascension Island. The PAFB, Florida station is connected to the Goldstone facility by leased wire lines and the monthly charges for this service has been included in the total operating costs per month. No costs appear for the two twx lines and two 5 kc analog channels for the reasons discussed in paragraph c. The costs versus information rate capability for the six station complex are depicted graphically in figures 5-5, 5-6, and 5-7.

Figure 5-1. Routing of Leased Services
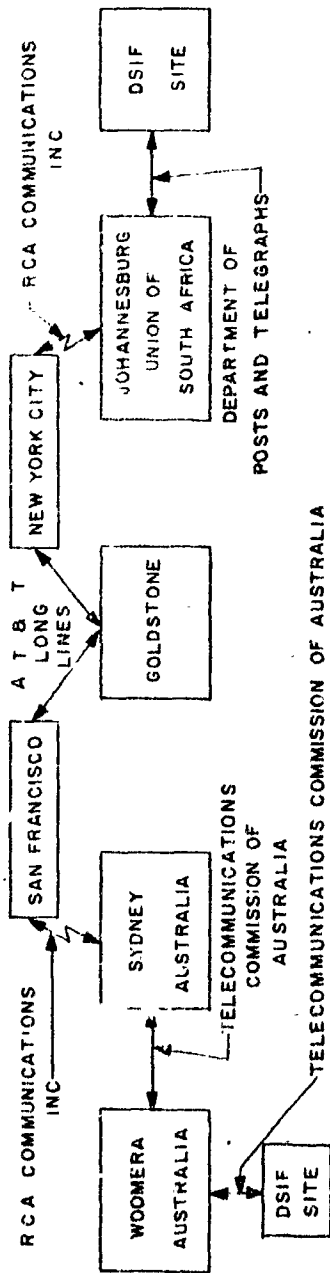
Service	DSIF to Woomera		Woomera to Sydney		Sydney to San Francisco		San Francisco to Goldstone		New York to Goldstone		Johannesburg to New York		DSIF to Johannesburg		Total Cost Per Channel	
	Instal. Cost	Mo. Cost	Instal. Cost	Mo. Cost	Instal. Cost	Mo. Cost	Instal. Cost	Mo. Cost	Instal. Cost	Mo. Cost	Instal. Cost	Mo. Cost	Instal. Cost	Mo. Cost	Instal. Cost	Mo. Cost
60 WPM TELETYPE With ARQ	Unknown		N.A.	$2325		$9107	$50	$699.78	$50	$2790.83		$8710	Unknown		$100	$23,632.61
100 WPM TELETYPE	Unknown		N.A.	$3240		$12,547	$50	$834.73	$50	$3446.54		$12,000	Unknown		$100	$32,170.2?

Service	Equip. and Engineering Cost	Bldg. and Facilities Cost	Installation Cost	Shipping Cost	Total Fixed Cost	Total Operating Cost/Month
2 TWX Lines +1 1 KC Voice Chnl.	1,147,572	78,000	236,500	54,494	1,516,566	53,388
2 TWX Line +2 5 KC Analog Chnl.						
110 CPS Digital 150 BITS/SEC	1,147,572	78,000	236,500	54,494	1,516,566	53,388
1 KC Digital 1050 BITS/SEC	1,189,016	78,000	236,500	54,494	1,588,010	53,388
3 KC Digital 3000 BITS/SEC	1,435,216	78,000	236,500	54,494	1,774,210	53,388
5 KC Digital 5025 BITS/SEC	1,863,303	78,000	236,500	54,494	2,232,297	53,388
10 KC Digital 10,050 BITS/SEC	2,887,358	78,000	236,500	54,494	3,256,352	53,388
1 KC Analog	782,289	78,000	176,500	54,494	1,091,283	53,388
3 KC Analog	782,289	78,000	176,500	54,494	1,091,283	53,388
5 KC Analog	782,289	78,000	176,500	54,494	1,091,283	53,388
10 KC Analog	782,289	78,000	176,500	54,494	1,091,283	53,388

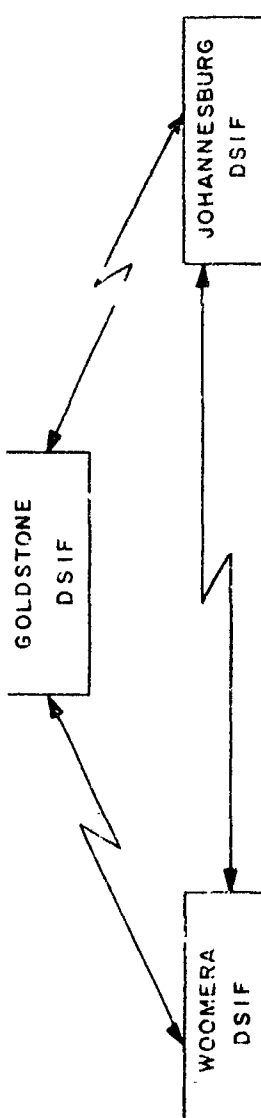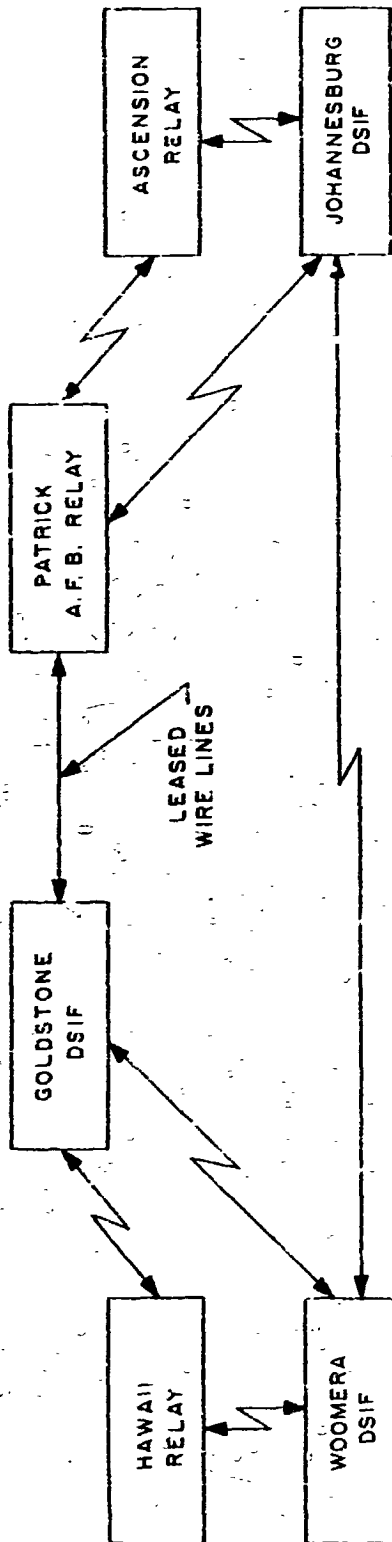Figure 5-2.   Costs of Three Station Communication Complex

Service	Equip. and Engineering Cost	Bldg. and Facilities Cost	Installation Cost	Shipping Cost	Total Fixed Cost	Operating Cost/Month	Leased Wire Cost/Month	Total Operating Cost/Month
2 TWX Lines +1 1 KC Voice Chnl.	1,379,469	97,500	283,000	62,267	1,822,236	68,184	3326	71,510
2 TWX Lines +2 5 KC Analog Chnl.								
110 CPS Digital 150 BITS/SEC	1,379,469	97,500	283,000	62,267	1,822,236	68,184	3326	71,510
1 KC Digital 1050 BITS/SEC	1,429,201	97,500	283,000	62,267	1,871,968	68,184	3326	71,510
3 KC Digital 3000 BITS/SEC	1,724,681	97,500	283,000	62,267	2,167,448	68,184	3326	71,510
5 KC Digital 5025 BITS/SEC	2,238,349	97,500	283,000	62,267	2,681,116	68,184	16,202	84,386
10 KC Digital 10,050 BITS/SEC	3,466,217	97,500	283,000	62,267	3,908,984	68,184	27,867	96,051
1 KC Analog	954,447	97,500	211,000	62,267	1,325,214	68,184	3326	71,510
3 KC Analog	954,447	97,500	211,000	62,267	1,325,214	68,184	3326	71,510
5 KC Analog	954,447	97,500	211,000	62,267	1,325,214	68,184	16,202	84,386
10 KC Analog	954,447	97,500	211,000	62,267	1,325,214	68,184	27,867	96,051

WOOMERA DSIF

GOLDSTONE DSIF

PATRICK AFB RELAY

JOHANNESBURG DSIF

LEASED WIRE LINES

Figure 5-3. Costs of Four Station Communication Complex

Service	Equip. and Engineering Cost	Bldg. and Facilities Cost	Installation Cost	Shipping Cost	Total Fixed Cost	Operating Cost/Month	Leased Wire Cost/Month	Total Operating Cost/Month
2 TWX Lines +1 / 1 KC Voice Chanl.	2,201,085	156,000	473,000	101,738	2,931,823	106,776	3,326	110,102
2 TWX Lines +2 / 5 KC Analog Chnl.								
110 CPS Digital / 150 BITS/SEC	2,201,085	156,000	473,000	101,738	2,931,823	106,776	3,326	110,102
1 KC Digital / 1050 BITS/SEC	2,283,973	156,000	473,000	101,738	3,014,711	106,776	3,326	110,102
3 KC Digital / 3000 BITS/SEC	2,776,373	156,000	473,000	101,738	3,507,111	106,776	3,326	110,102
5KC Digital / 5025 BITS/SEC	3,632,549	156,000	473,000	101,738	4,363,287	106,776	16,202	122,978
10KC Digital / 10,050 BITS/SEC	5,679,663	156,000	473,000	101,738	6,410,401	106,776	27,867	134,643
1 KC Analog	1,480,957	156,000	353,000	101,738	2,091,695	106,776	3,326	110,102
3KC Analog	1,480,957	156,000	353,000	101,738	2,091,695	106,776	3,326	110,102
5 KC Analog	1,480,957	156,000	353,000	101,738	2,091,695	106,776	16,202	122,978
10KC Analog	1,480,957	156,000	353,000	101,738	2,091,695	106,776	27,867	134,643

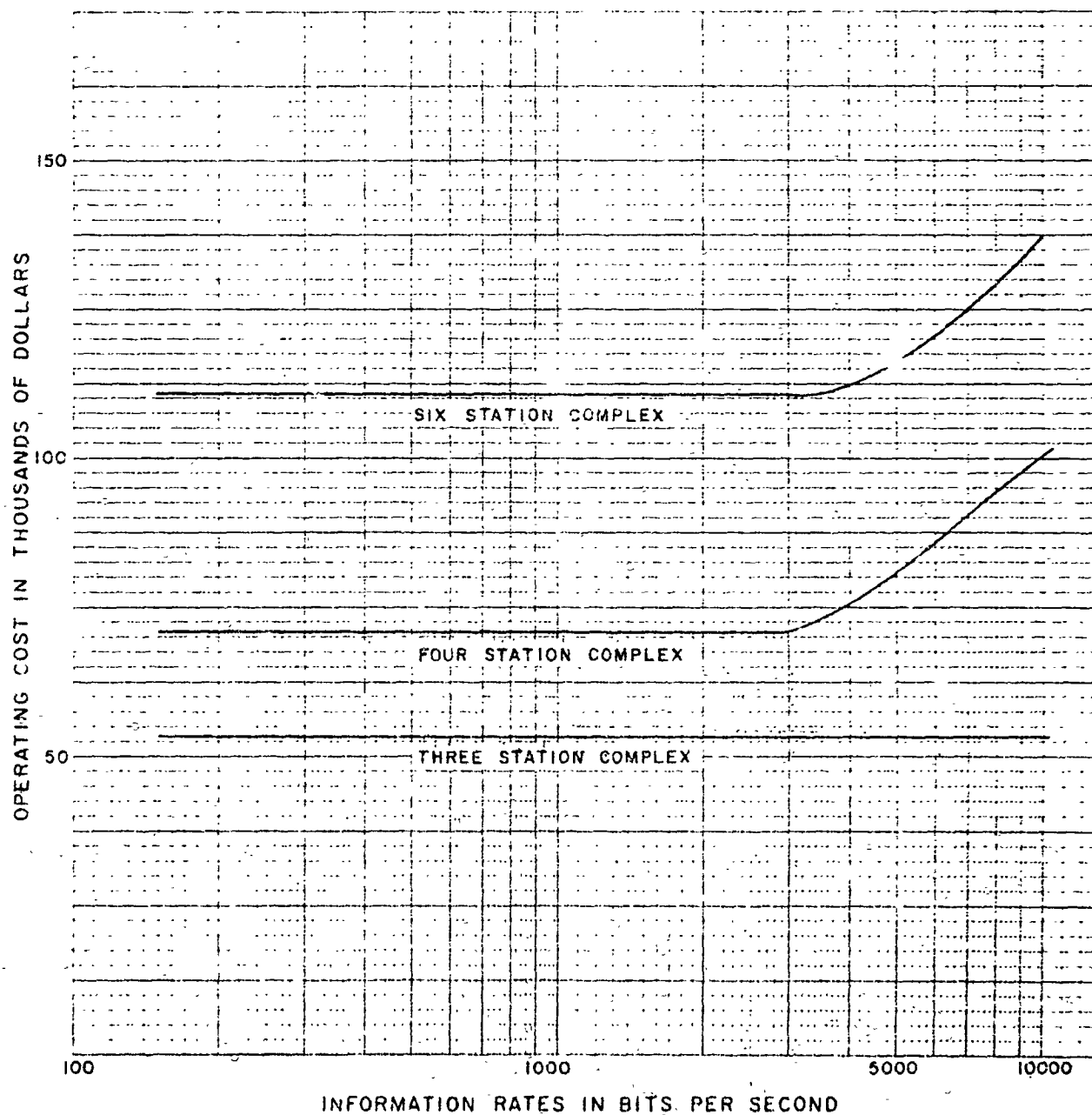Figure 5-4. Costs of Six Station Communication Complex
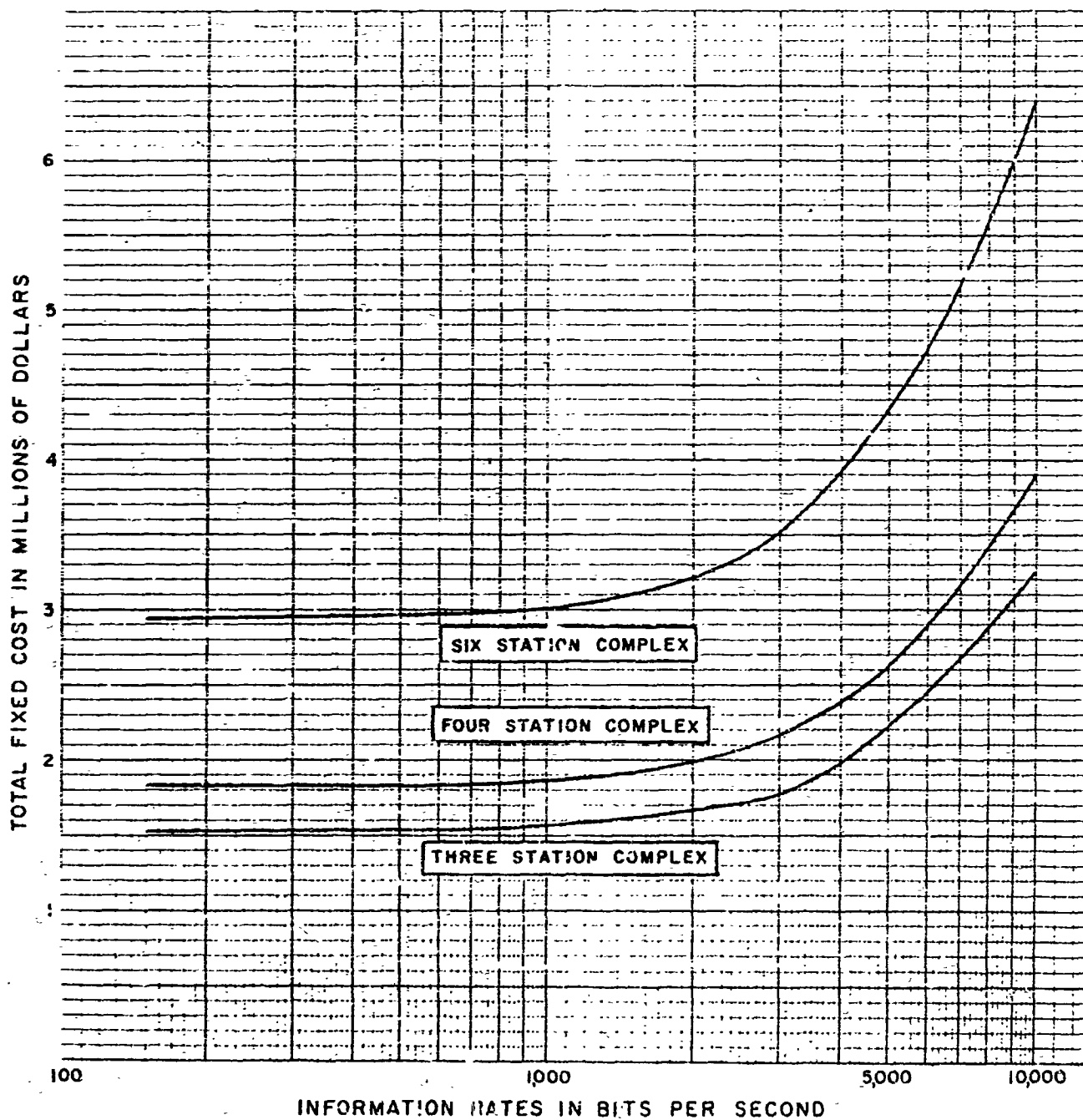
Figure 5-5. Operating Costs vs Information Rate

Figure 5-6. Total Fixed Cost vs Information Rate, Digital Data Channel
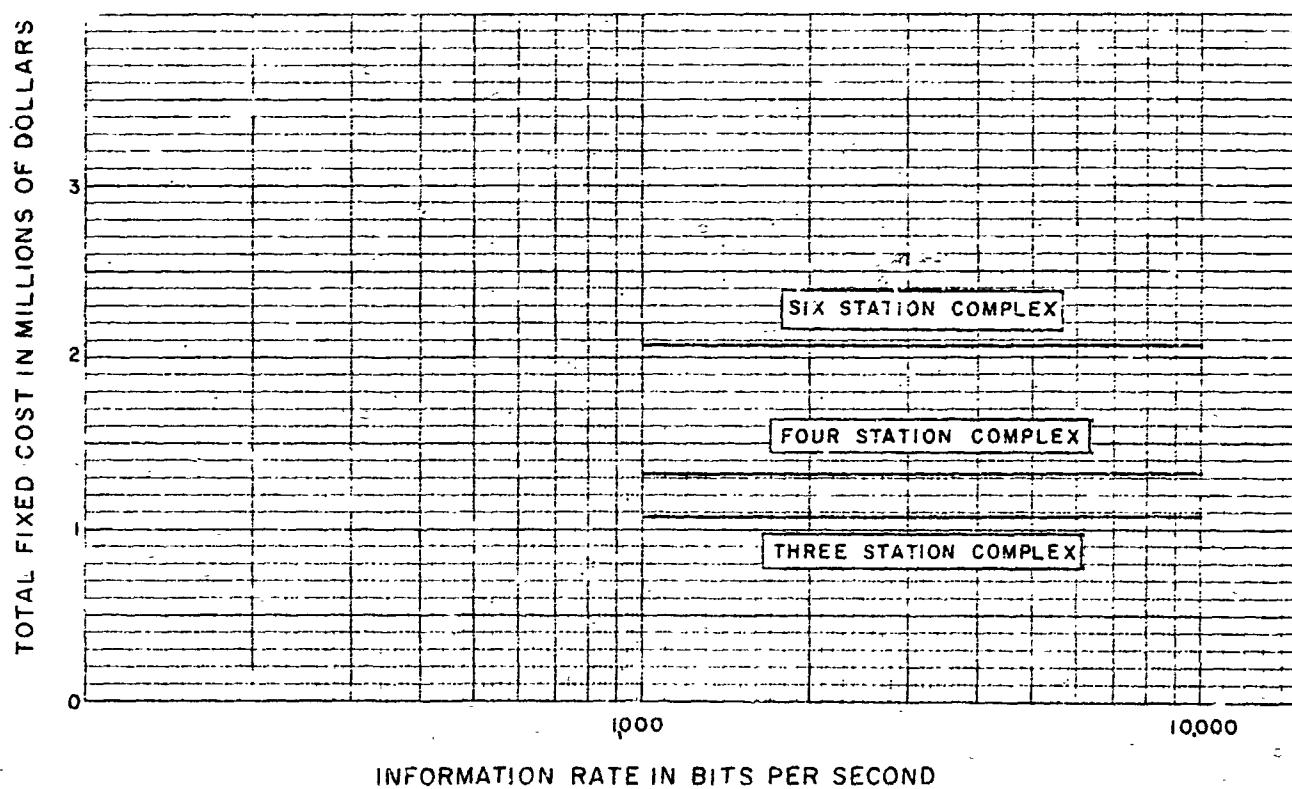
Figure 5-7. Total Fixed Cost vs Information Rate,
Analog Channels

Section VI

SUMMARY

The reliabilities and the costs of the three communication complexes studied have been discussed in separate sections of this report. The results of these individual studies have been combined and analyzed in this section in the form of charts and graphs. Tables 6-1 and 6-3 indicate the cost variation versus information rate capability and reliability for analog and digital data channels respectively. Comparison of the relative merits of these two types of data transmission can be determined readily from the tables. For example, consider that a complex reliability above 70 percent is required. For analog data transmission (see table 6-1), a six-station complex is the only one that can provide this reliability and the information rate capability is limited to a maximum of a 3-k channel. For digital data transmission (see table 6-2), both a four-and six-station complex can provide a reliability above 70 per cent. At this reliability, a four-station complex can provide information rates of 1050 bits per second or 150 bits per second at a quality factor of 99.9 per cent and a six-station complex can provide information rates of 5025, 3000, 1050, or 150 bits per second at this same quality factor.

Tables 6-2 and 6-4 indicate the cost variation versus information rate and apparent reliability. (Apparent reliability has been defined in paragraph 3.6.1 of this report.) The tables may be used in the same manner as tables 6-1 and 6-3. Figure 6-1 graphically indicates the cost variation with reliability for the analog data channels studied, and figure 6-2 is a graphic illustration of the same information for the digital data channels studied. Figure 6-3 is a comparison of monthly operating costs. It

should be noted that the operating costs for a three-station communication complex is constant for all information rate capabilities while the operating costs of the four and six station communication complexes start rising for information rates requiring bandwidths greater than 3 kc. This rise is the result of the costs for the leased wire service between Patrick and Goldstone which increase with bandwidth requirements. The use of wire lines are required for this circuit because the FCC will not allocate high frequency channels to establish networks within the continental limits of the United States.

Figure 6-4 shows the variations of operating costs versus the reliabilities supplied by the three complexes studied. The effects of the costs of the leased land lines upon the operating costs of the four-and six-station complex are also obvious in this set of curves.

Bandwidth / Reliability	1 KC/S	3 KC/S	5 KC/S	10 KC/S
23%				$1,091,283 3 Station Complex
28.5%				$1,325,214 4 Station Complex
30%			$1,091,283 3 Station Complex	
36.5%		$1,091,283 3 Station Complex		
38%			$1,325,214 4 Station Complex	
46%				$2,091,695 6 Station Complex
46.5%		$1,325,214 4 Station Complex		
50%	$1,091,283 3 Station Complex			
57%			$2,091,695 6 Station Complex	
63%	$1,325,214 4 Station Complex			
65%		$2,091,695 6 Station Complex		
78%	$2,091,695 6 Station Complex			

Table 6-1. Total Fixed Costs vs Reliability - Analog Data Channels

Bandwidth_____Apparent Reliability	1 KC/S	3 KC/S	5 KC/S	10 KC/S
29.5%				$1,091,283 3 Station Complex
35%				$1,325,214 4 Station Complex
37%			$1,091,283 3 Station Complex	
42%		$1,091,283 3 Station Complex		
45%			$1,325,214 4 Station Complex	
52%		$1,325,214 4 Station Complex		
53%				$2,091,695 6 Station Complex
56%	$1,091,283 3 Station Complex			
64%			$2,091,695 6 Station Complex	
69%	$1,325,214 4 Station Complex			
71%		$2,091,695 6 Station Complex		
84%	$2,091,695 6 Station Complex			

Table 6-2. Total Fixed Costs vs Apparent Reliability - Analog Data Channels

Bandwidth / Bit Rate / Reliability	0.1 KC/S 150 B/S	1 KC/S 1050 B/S	3 KC/S 3000 B/S	5 KC/S 5025 B/S	10 KC/S 10,050 B/S
31%					$2,256,352 3 Station Complex
39%					$3,908,984 4 Station Complex
41%				$2,232,297 3 Station Complex	
47%			$1,774,210 3 Station Complex		
52%				$2,681,116 4 Station Complex	
59%					$6,410.401 6 Station Complex
60%		$1,588,010 3 Station Complex	$2,167,448 4 Station Complex		
69%	$1,516,566 3 Station Complex				
70%				$4,363,287 6 Station Complex	
74%		$1,871,968 4 Station Complex			
76%			$3,507,111 6 Station Complex		
83%	$1,822,236 4 Station Complex				
85%		$3,014,711 6 Station Complex			
90%	$2,931,823 6 Station Complex				

Table 6-3. Total Fixed Costs vs Reliability - Digital Data Channels   6-5

Reliability \\ Bandwidth Bit Rate	0.1 KC/S 150 B/S	1 KC/S 1050 B/S	3 KC/S 3000 B/S	5 KC/S 5025 B/S	10 KC/S 10,050 B/S
36%					$3,256,352 3 Station Complex
45%					$3,908,984 4 Station Complex
47%				$2,232,297 3 Station Complex	
54%			$1,774,210 3 Station Complex		
57%				$2,681,116 4 Station Complex	
65%					$6,410,?1 6 Station Complex
66%		$1,588,010 3 Station Complex	$2,167,448 4 Station Complex		
75%	$1,516,566 3 Station Complex				
76%				$4,363,287 6 Station Complex	
80%		$1,871,968 4 Station Complex			
82%			$3,507,111 6 Station Complex		
89%	$1,822,236 4 Station Complex				
91%		$3,014,711 6 Station Complex			
96%	$2,931,823 6 Station Complex				

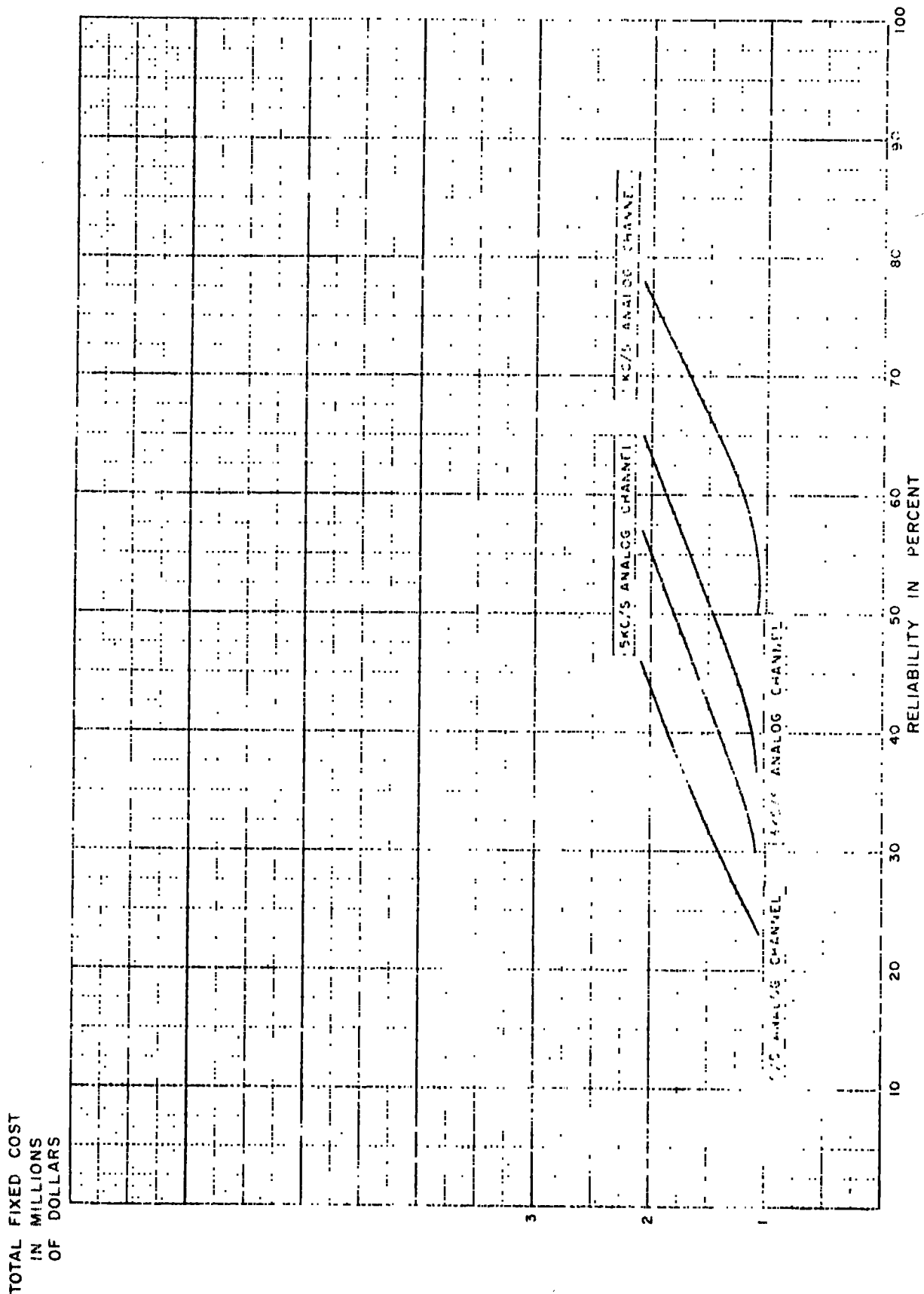**Table 6-4. Total Fixed Costs vs Apparent Reliability – Digital Data Channels**

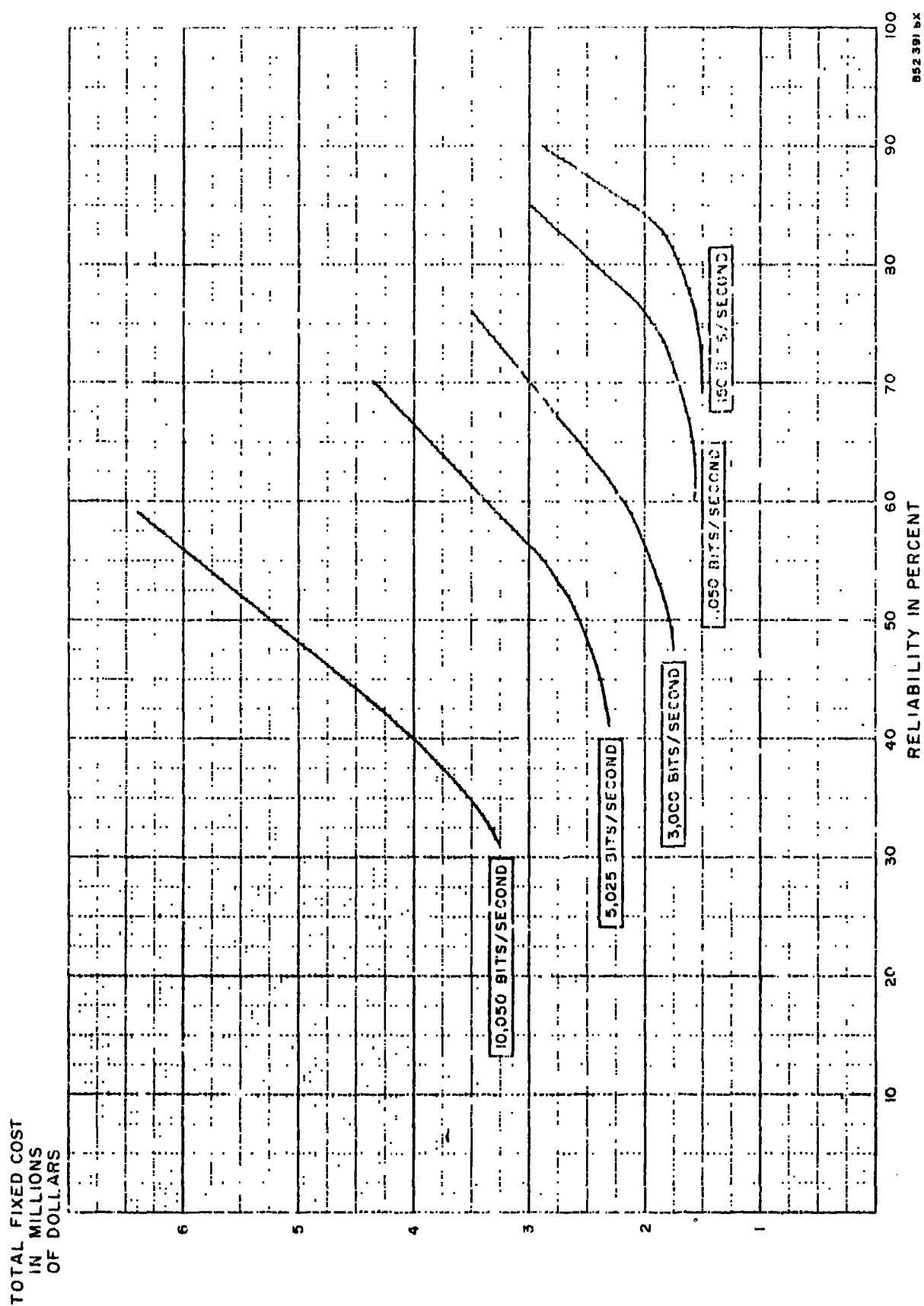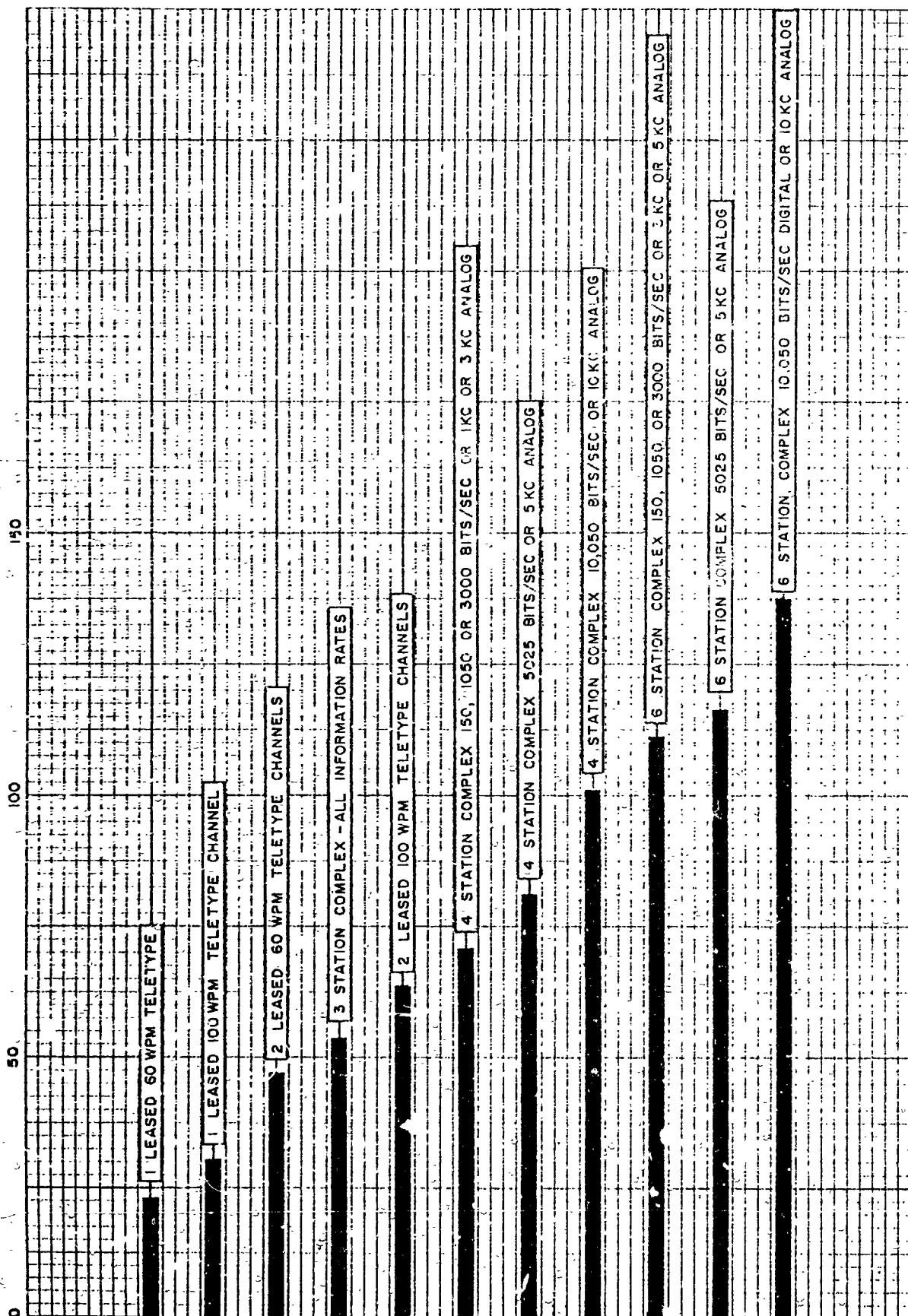Figure 6-1. Total Fixed Cost vs Reliability, Analog Data Channels

Figure 6-2. Total Fixed Cost vs Reliability. Digital Data Channels

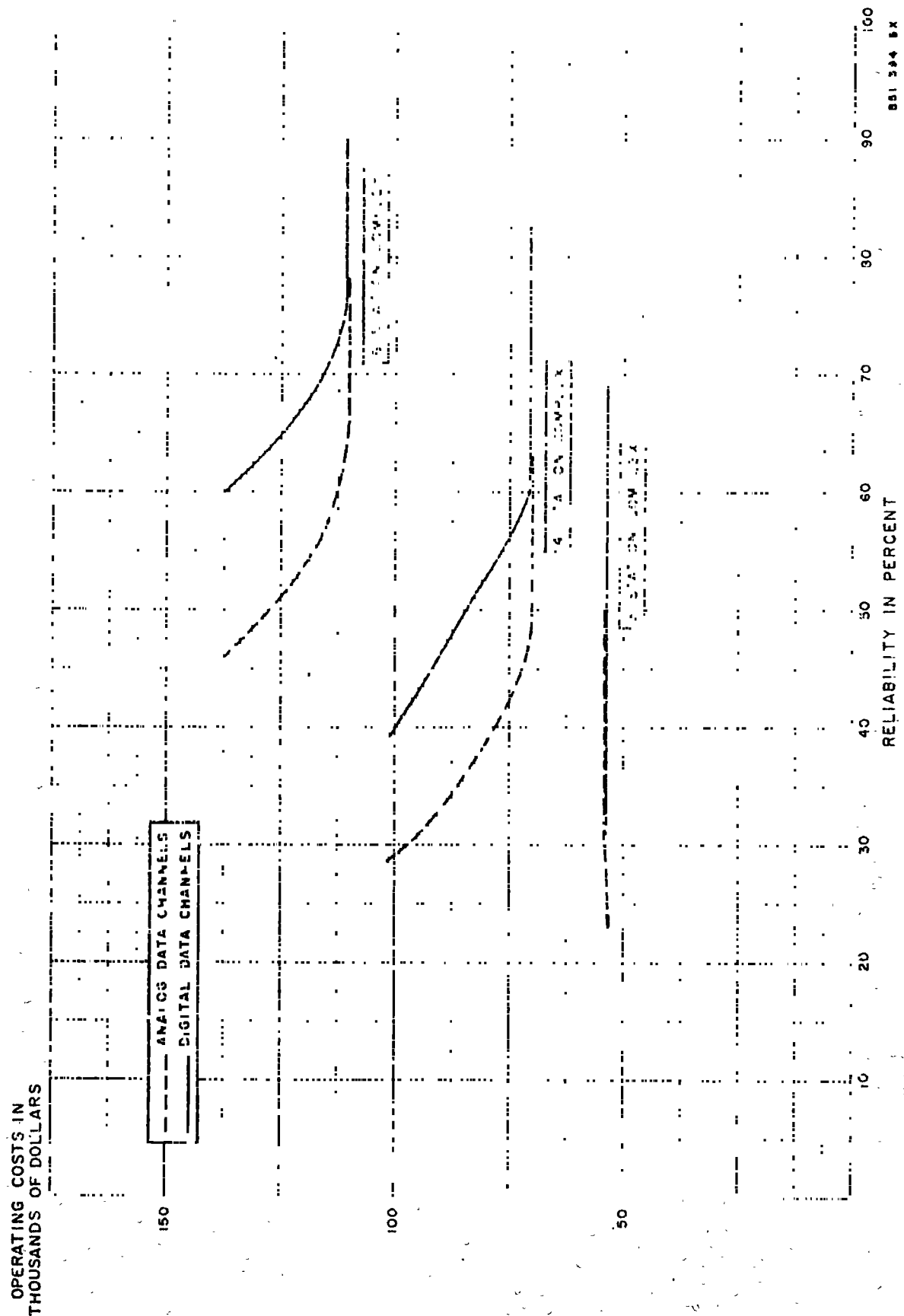Figure 6-3. Comparative Monthly Operating Costs

Figure 6-4. Variation of Operating Costs vs Reliability

Section VII

CONCLUSIONS

To select an optimum communication system to be used with the three Deep Space Instrument Facilities Stations, consideration must be given to cost, reliability required, and information rate capability of the systems under surveillance. These three factors exert an effect upon each other. In general it can be stated that:

1. When costs are held constant, reliability is varied inversely with information rate capability.

2. When reliability is held constant, costs increase with an increase in information rate capability.

3. When information rate capability is held constant, costs increase for an increase in reliability.

If selection of a communication system is to be considered upon the basis of cost alone, high reliability can only be achieved by accepting low information rate capability. Thus, if funds are limited, a compromise must be made between reliability and information rate capability. It should be pointed out that this relationship does not follow a smooth curve for digital transmissions but progresses in a step-like manner because, in the practical sense, reliability is dependent upon the number of stations in the system, while the information rate capability is dependent upon the amount of terminal equipment. For analog transmissions, the relationship of information rate capability to reliability tends to follow a smooth curve because both information rate and reliability are functions of bandwidth, and bandwidth is continuously variable.

If selection of a communication system is to be considered upon the basis of reliability alone, high information rate capability can only be achieved by increasing the cost. As higher information rate capability is added to a system, the costs for digital transmission must increase for two reasons, the costs of the additional terminal equipment and the costs of additional stations to maintain the selected reliability. It is obvious that this curve also progresses in a step-like manner. This is also true for analog transmissions because a selected reliability can only be maintained by the addition of stations to the system.

If selection of a communication system is to be considered upon the basis of information rate capability alone, high reliability can only be achieved by increasing the cost. As higher reliability requirements are placed upon a system, the costs must increase to provide additional stations to supply that reliability. This curve also progresses in a step-like manner because the costs of station additions are quantized.

The reliabilities of leased services and the reliabilities of a privately-owned system are similar for a given information rate because both are dependent upon identical high frequency propagation vagaries. Therefore, the use of leased services will result in the sacrifice of information rate and operating control.